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ABSTRACT

Included in the unit are ideas related to: categorizing (classifying), quantifying, model making, and developing terminology. Laboratory experiences include activities to investigate: similarities and differences, making and using keys, the relative nature of measurement, making a physical model of an atom, models for probability (heredity), and changes in language. These laboratory experiences are inquiry-oriented, although designed to contribute to the development of understanding how a scientist behaves toward his world. The format for each laboratory experience is as follows: Introduction, Materials and Equipment, Collecting Data, and Follow-up. (BR)

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IDEA-CENTERED LABORATORY SCIENCE

(I-CLS)

Unit B. How a Scientist Behaves Toward His World

A scientist assumes that the world is orderly. He follows this assumption in the way that he behaves toward it. He arranges the things that he observes in convenient groups, which are, as far as possible, natural groups. That is, they are based on discoverable characteristics; they have distinguishable limits; and they show meaningful relationships to one another.

A scientist is concerned with measurable *quantities* rather than *qualities* that rest on someone's judgment. Galileo said that "science attempts to measure all things and reduce *all* things to measure." The scientist deals, therefore, with material things---things that can be measured. As a person, a scientist may recognize the importance of value judgments: how "good" something is, or how "beautiful," but as a scientist he is only concerned with *quantities* and *measurements*.

A scientist operates in the whole universe, from the realm of the almost unbelievably minute to that of the almost unbelievably vast. He also operates from the realm of the simple to the realm of the almost unbelievably complex. In order to make principles and concepts within these ultimate boundaries of reality understandable to himself and others, he expresses his ideas in simple forms and then applies these to the more complex things and their interrelationships. In this way he is able to get across to non-scientists important understandings about the world.

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Unit B. How a Scientist Behaves Toward His World

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Idea of Categorizing B.1.

Idea Bridge: Similarities and Differences

Although living things actually form gradients so that there are no sharp lines which divide them, scientists have found that there are enough similarities and differences in living things so that they can be grouped for study.

The scientist is able to study man by examining samples. He does not have to examine every man in the world. You may have heard someone say, "He's the very image of his father." Is he? Are there any differences? Are these gross or subtle differences? You may have heard the saying, "As alike as two peas in a pod." Are any two peas really alike, even though they do grow in the same pod? Are there differences between them if we examine them closely?

The scientist studies groups rather than individuals. He makes these groups by looking for similarities, and then separates them from other groups, and recognizes sub-groups within them by looking for differences. Once he has established groups and sub-groups he is able to make a key that will help others to identify individuals as members of these groups and sub-groups.

In this way, the scientist studies insects as a large and inclusive group because of their many characteristics in common (similarities or likenesses). Then he distinguishes sub-groups within this large group because of their differences. These smaller groups can then be studied separately. The scientist does this in the case of both living and non-living things.

LABORATORY EXPERIENCE B.1.a.

Recognizing Properties

Introduction:

How are a stone and a butterfly different? How are they similar or alike? Is it easier to list similarities or differences? Why? List the ways a tree and a butterfly are similar or alike. Is this easier than comparing a stone and a butterfly? Why? Try comparing a fly and a mosquito. Is it easier or harder? Why?

When you made these comparisons, you were recognizing the characteristics of these things. Scientists call the characteristics of material objects, their properties.

Below is a list of some of the properties of matter. If all matter has any one of them, it is a general property. If one of them fits only some kinds of matter, it is a specific property. For example, color is a general property of matter, but red color is a specific property of anything that appears red.

Mass	The amount of matter in an object
Weight	The measurement of the earth's attraction for the mass
Inertia	The characteristic that causes matter to stay at rest or stay in uniform motion unless acted upon by an outside force
Volume	The measure of the amount of space taken up
Impenetrability	Two objects cannot occupy the same space at the same time
Porosity	Spaces between molecules and groups of molecules
State of matter	The form (solid, liquid, gas) in which matter exists
Density	The ratio of the mass to its volume
Hardness	The resistance of a solid material to scratching by another substance
Color	The wave-length of light which is reflected or emitted
Brittleness	The property of a material that causes it to be fractured or broken when a force is exerted on it
Malleability	The property of matter that permits it to be formed into shape by hammering, pressing, rolling, or bending
Ductility	The property of matter that permits it to be pulled out into thin threads or wires
Transparency	The property of matter that permits light to pass through a material, so that objects can be clearly distinguished as one looks through it
Translucency	The property that allows light to pass through a material, while objects cannot be clearly distinguished as one looks through it
Opaqueness	The property that prevents light from passing through a material
Solubility	A measure of the amount of a given substance that will dissolve in another substance
Boiling point	The temperature at which a liquid boils
Freezing point	The temperature at which a liquid becomes a solid

Materials and Equipment:

- sulfur
- salt
- rubber ball
- copper wire
- clay
- glass
- marbles
- piece of string

Collecting Data:

Test each of the kinds of matter listed above for each of the listed properties. Which properties seem to be general properties? Can you think of any kind of matter that would not have these general properties? Which of your senses did you use in making your observations? How could you extend your senses in order to make more precise observations? What devices or instruments would you use to do this?

Follow-Up:

Continue your study using living things (animals and plants), or things that were recently alive. Make a list of as many such things as you have available. Then list the general properties of these things, and the specific properties.

Compare these things with the non-living things that you have studied. What general properties do they have in common. Do they have any specific properties in common?

LABORATORY EXPERIENCE B.1.b.

Using Similarities and Differences to Group Things

Introduction:

There is more to observation than just the act of observing. We need to systematize our observations; to put them into categories. One simple way to do this is to divide them into two general groups: (1) "How are things similar or alike?" and (2) "How are they different or not alike?"

When we do this we sometimes find that the differences serve to point up or emphasize the similarities. These, in turn, show us meaningful relationships. In this way the classification systems that we work out may serve for something more than mere convenience.

Materials and Equipment:

Pencils
Paper clips
Postage stamps
Nails
Leaves of common kinds of trees
Locks of hair
Carrots
Apples
Small pieces of wood
Grains of corn
Pens
Books
Magazines
Envelopes
Paper sacks

Note: Substitutions can be made for most of these things.

Collecting Data:

1. Compare pairs of very different non-living objects:

   a. A pencil and a paper clip
   b. A postage stamp and a nail
   c. A clothes pin and a teaspoon
   (You may substitute any other unlike pairs of non-living objects)

   Do the members of the pair have anything in common? What common characteristics do they possess? In what ways are they different? Find as many differences as you can.

2. Compare pairs of very different living objects (or objects of living origin):

   a. A leaf and a lock of hair
   b. A carrot and an apple
   c. A small piece of wood and a grain of corn
   (You may substitute any other unlike pairs of living objects, or objects of living origin.)

Do the members of the pair have anything in common? What common characteristics do they possess? In what ways are they different? Find as many differences as you can.

What similarities are there between the living objects that you have examined and the non-living objects? What differences are there? What characteristics do the living objects have that would lead you to consider that they constitute a natural group? Do the non-living objects constitute a natural group? Why or why not?

3. Compare groups of similar non-living objects:

   a. Pencils and pens
   b. Books and magazines
   c. Envelopes and paper sacks

Why are the members of each group considered similar? Are they more similar than different? Can you answer this question quantitatively? Are there any intermediate forms that would tend to "bridge the gap" between the members of one group and members of the other? Can you think of other similar non-living groups that you could add to these?

4. Compare the leaves (or needles) of similar kinds of trees or shrubs:

   a. Different species of cherries and different species of poplars
   b. Different species of oaks and different species of maples
   c. Different species of pines and different species of spruces

Try to find at least one major characteristic that distinguishes the species of one group from those of the other group. Can you find any other distinguishing characteristics in each case? In what ways are the species of one group similar to those of the other group?

5. Now examine the species of each group in relation to one another. Are all kinds of cherry leaves similar? In what ways? Are all poplar leaves similar? All oak leaves? All maple leaves? All pine needles? All spruce needles? Are these natural groups, or are they merely something set up for the convenience of botanists?

Follow-Up:

Observe similarities and differences in animals. What similarities and differences are there in dogs and cats? In pigeons and robins? In fishes and turtles? To what extent are all birds alike? What are some birds that are very different from most other birds? How are they different?

Do you think that degree of similarity may indicate closeness of relationship? Why? Why do we say that certain animals belong to "the cat family?" To the "dog family?" What animals do we include in each of these families? Is there more individual variation among man-made things or among living (or formerly living) things? Why do you think this might be so?

LABORATORY EXPERIENCE B.1.c.

Making and Using Keys

Introduction:

It has been said that man is the queerest of all living things but that nevertheless the other 1,165,999(or more)species of living things are each worth knowing. It would require long rows of book shelves to hold the volumes that have been written about living things. It would take several lifetimes to study all of the known information. Furthermore, many other highly interesting and valuable facts remain to be discovered---perhaps more facts than are already known.

How can scientists know where to start? How can they discover relationships that give meaning and order to these 1,165,999 kinds of living things? Can they be grouped so a scientist can study likenesses within a group as well as differences between groups? How would you go about grouping 1,165,999 species? What would your groups be? Could each group be subdivided into two groups, or would you have to have more than two?

Let's try grouping other objects first, and then return to the idea of grouping living things.

Materials and Equipment:

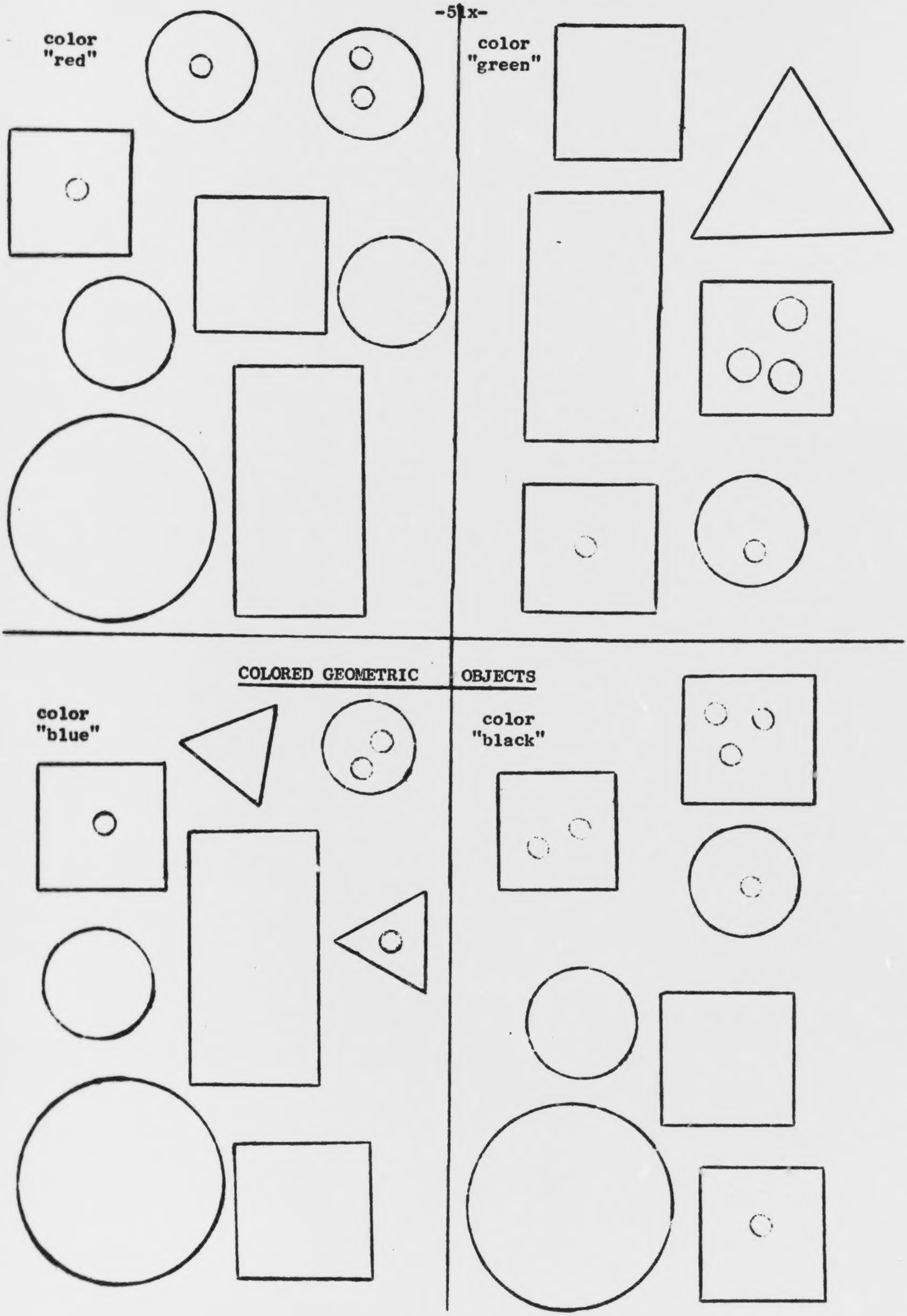
Sheet of paper showing geometric shapes

Eighteen miscellaneous objects: block of wood, block of plastic, toothpick, long stick, plastic straw, paper straw, long nail, small nail, thumbtack, steel tack, screw, piece of wire, wooden dowel, paper clip, rubber band, piece of string, marble, postage stamp

Collecting Data:

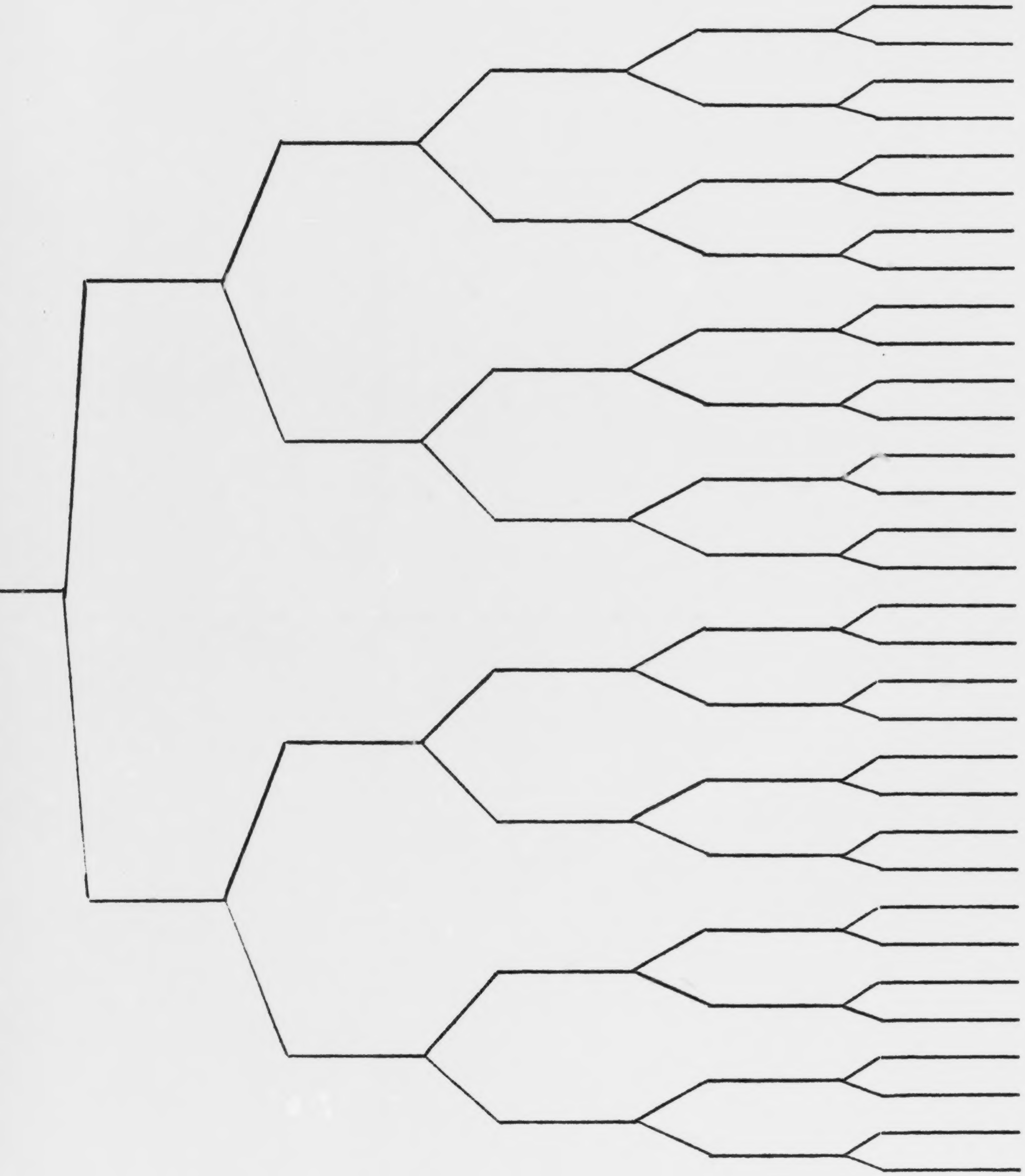
Color and cut out the geometric shapes on the following page. Punch holes as indicated. Place all the pieces of colored paper on your desk. Put them into two groups. What is the basis for your "either/or" choice? Don't feel you must use the same basis for choice that other students use. Remember there is no right or wrong answer to this grouping. Use what seems reasonable to you personally. Record the basis for your choice on Data Sheet No. 1. Now subdivide each group by other "either/or" choices and again record the basis for your choices on the Data Sheet. Continue to make "either/or" choices until you have a single geometric shape in each sub-group. Encircle it to show it is the last of the "either/or" choices.

Have your teacher use your key and ask you questions to identify a particular piece that you have mentally selected. Now let your teacher select a piece and you identify it by asking the questions. If your key is well done, any piece can be identified, even though your key is completely unlike any other student's key.


color
"red"
color
"green"
color
"blue"
color
"black"

COLORED GEOMETRIC OBJECTS

Data Sheet No. 1



Data Sheet No. 2

1. Go to 2.
1. Go to _____.

2. Go to 3.
2. Go to _____.

3. Go to 4.
3. Go to _____.

4.
4.

5.
5.

6.
6.

7.
7.

8.
8.

9.
9.

10.
10.

11.
11.

12.
12.

Setting Up A Hypothesis:

With your teacher's help, state a hypothesis about grouping things by "either/or" choices.

Testing Your Hypothesis by Collecting More Data:

Now put 18 miscellaneous objects (See list of Materials and Equipment above) on your desk. Separate the objects into two groups by an "either/or" choice. This time record the basis for your choice on Data Sheet No. 2. This is another way of setting up a key. Subdivide each group by other "either/or" choices. Record the basis for your choices on the Data Sheet. Continue to subdivide by making "either/or" choices until you have only a single object in each subgroup. Encircle it to show that it is the last of the "either/or" choices. Cooperate with another student this time to see if your key "works" in identifying one selected object chosen mentally.

Reaching Conclusions:

A key based on "either/or" choices is called a dichotomous key. Is it possible to make such a key for all living things? Would it be easy? Would you have to discover microscopic differences or chemical differences in some cases? Would it be more reasonable to make a key for one group of animals, for example, insects, rather than for all animals? Would it be possible to key such plants as mosses? Fungi? What about microscopic animals such as paramecium, amoeba, *et cetera*?

Follow-Up:

Would it be possible to make a key for separating any group of objects into natural categories? Or do we have to limit the use of this method ("either/or" choice) to groups of objects that have *some* similarities as well as differences?

LABORATORY EXPERIENCE B.1.d.

Identifying Leaves

Introduction:

Scientists have made and used keys for categorizing rocks, flowers, birds, mammals and many other things, living and non-living. One of the easiest to understand and use, however, is a leaf key.

Materials and Equipment:

An understanding of a few necessary botanical terms that are used in describing leaves.(See accompanying chart of diagrams showing the meaning of terms)

A leaf key. The one given here is simplified, but it will enable you to identify many common trees.

Books containing descriptions and pictures of different kinds of trees common to the region where you are.
NOTE: There are many such books available. Some are simple "paperbacks"that can be purchased in bookstores or even in supermarkets. Others are "field books," designed to be used by students of outdoor biology. Probably the best of these is A Field Guide to Trees and Shrubs, by George A. Petrides, published by Houghton Mifflin Company, Boston. This one, however, is designed for the northeastern and north central United States and southeastern and south central Canada. It has only limited value elsewhere. Other similar field guides, however, are available for other areas.

Collecting Data:

Use the key to identify the leaves that are pictured in the accompanying pages.

Notice that on the key there are two sentences numbered "1", two sentences numbered "2", two numbered "3", and so on. Start by reading both of the sentences numbered "1". See which of these best describes the leaf you are trying to identify. Follow the directions after that sentence. For example, if you decide that "leaves are needles or scale-like," you would go to number 14. At 14 you would find two more sentences. Read each of these and decide which one best describes your leaf; then follow the directions after that sentence. In this way you can use your key as a "road map" which leads you from one place to the next until you reach your final destination, the name of the tree from which your leaf came.

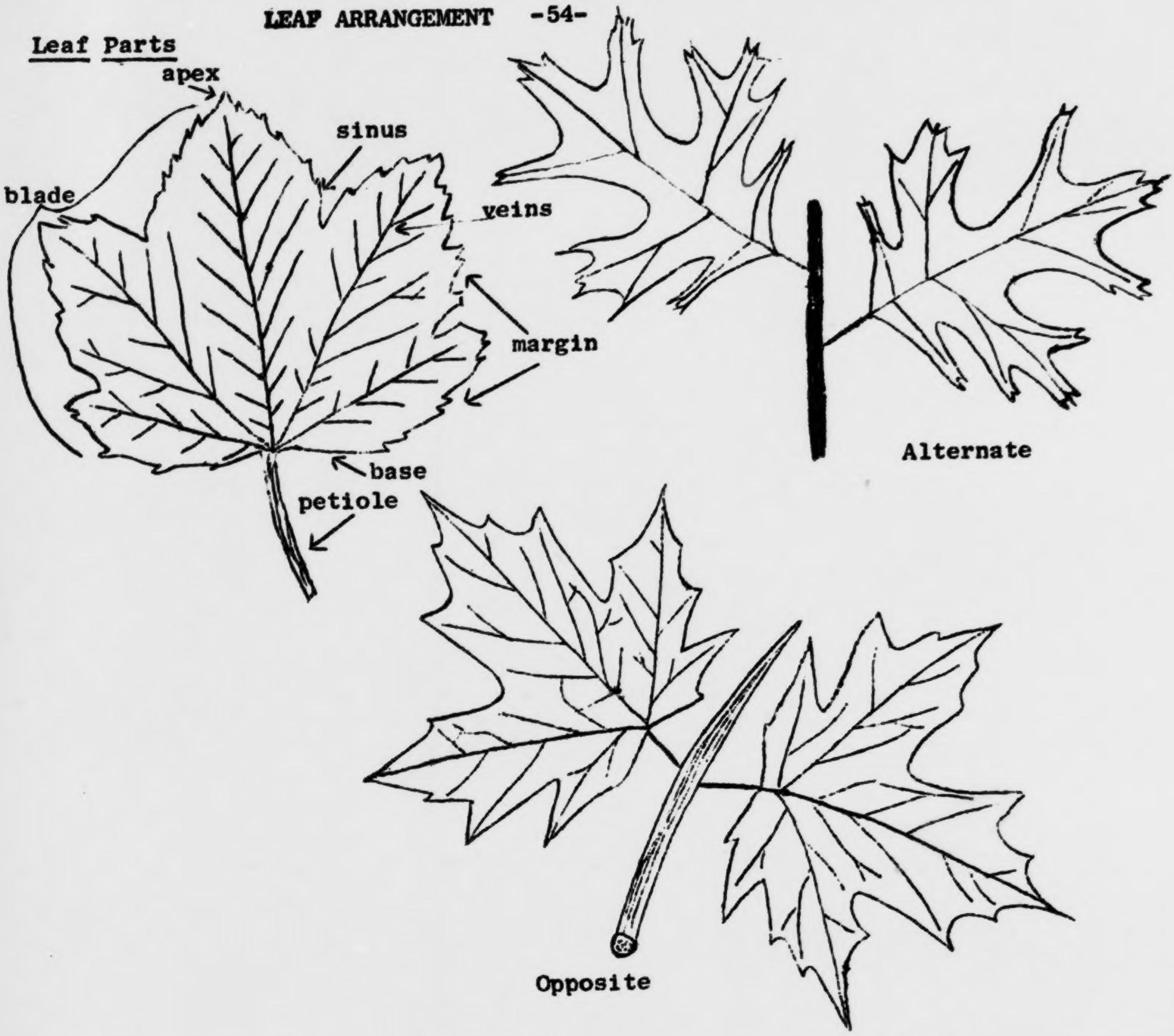
When you have found what you believe to be the proper name for your tree, check in a tree book (use the Index) to see if the picture there looks like the leaf you have.

Follow-Up:

Take your key outdoors and see if you can use it to identify real leaves.

LEAF ARRANGEMENT

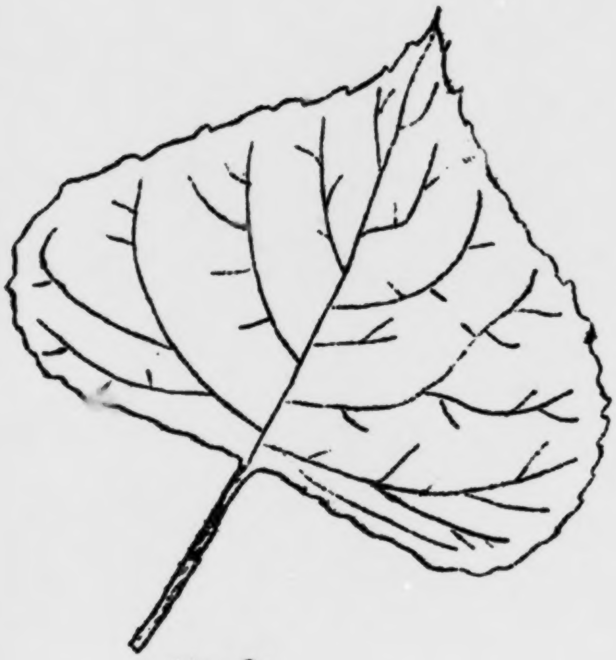
Leaf Parts


apex
sinus
blade
veins
margin
base
petiole

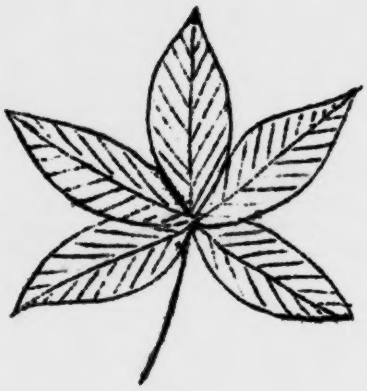
Alternate

Opposite

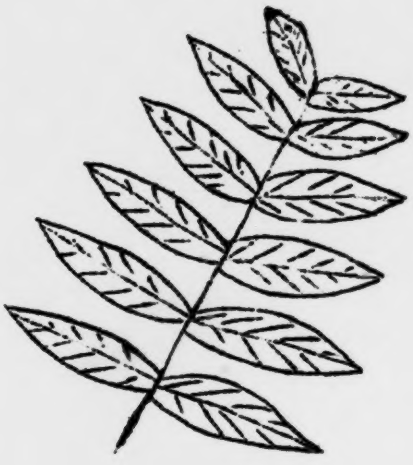
SINGLE LEAVES



Simple

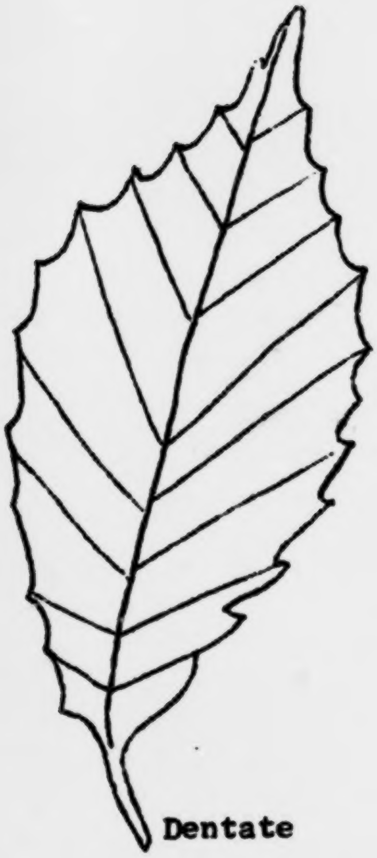


Palmately Compound

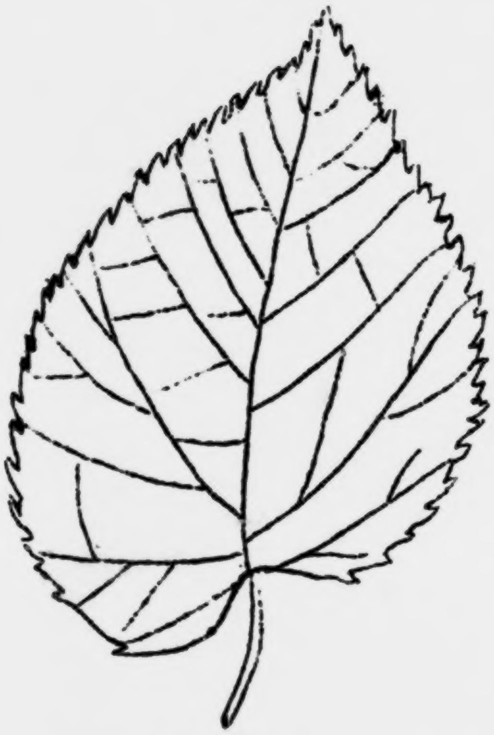


Pinnately Compound

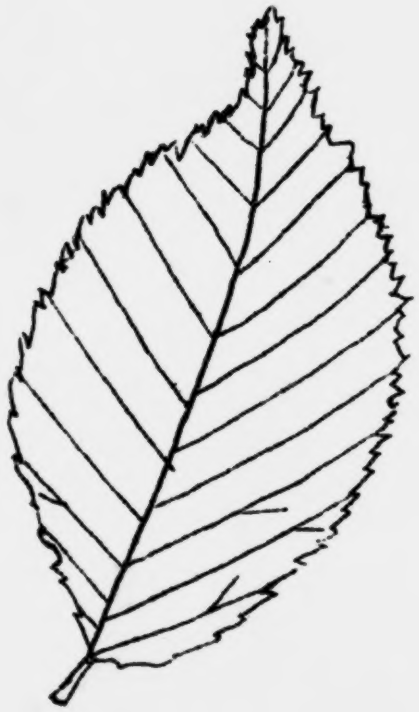
MARGINS



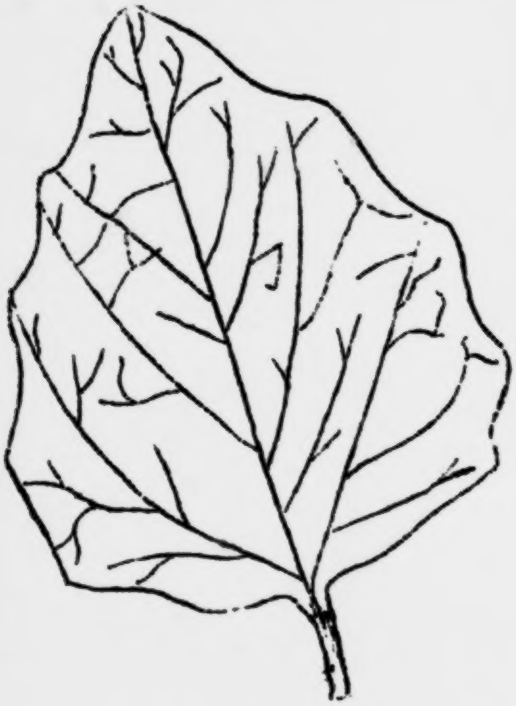
Dentate



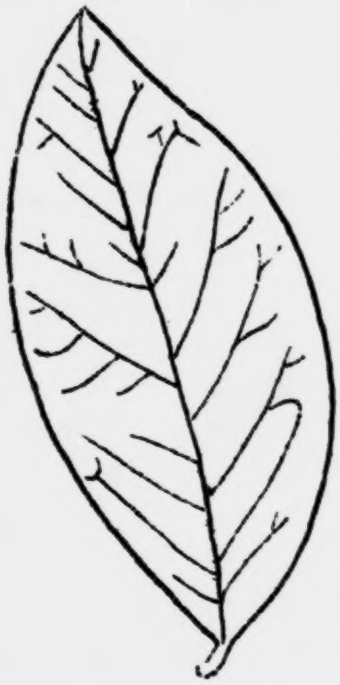
Serrate



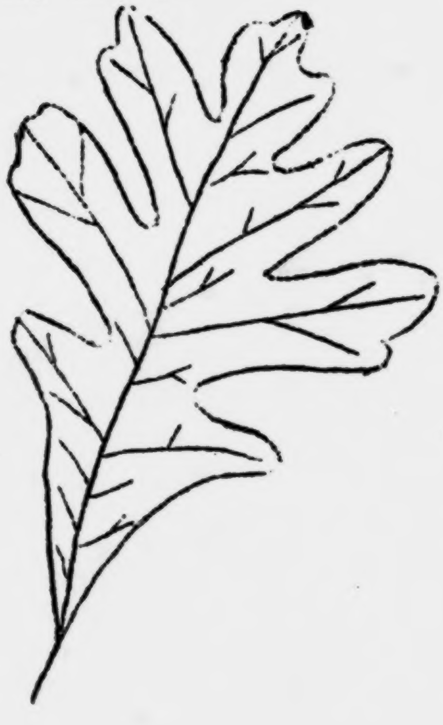
Doubly Serrate



Undulate

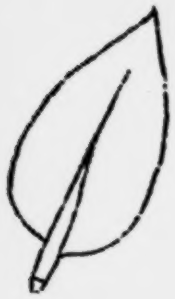


Entire

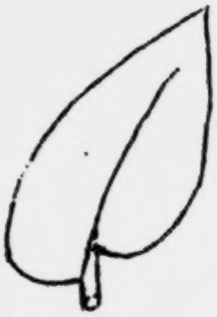


Lobed

BASE OF LEAF

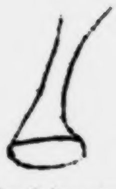


Symmetrical

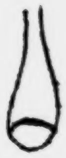


Asymmetrical

PETIOLE

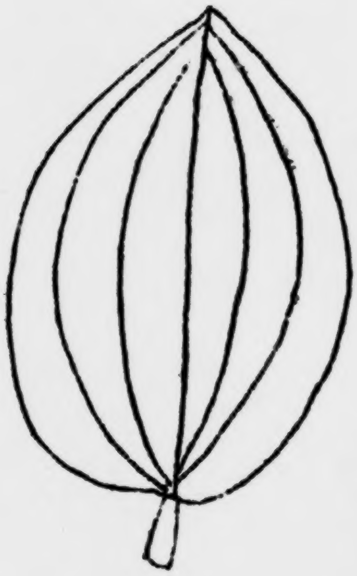


Flattened

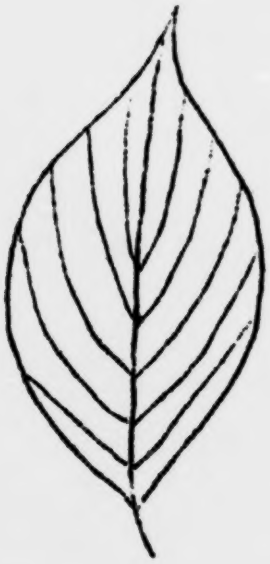


Round

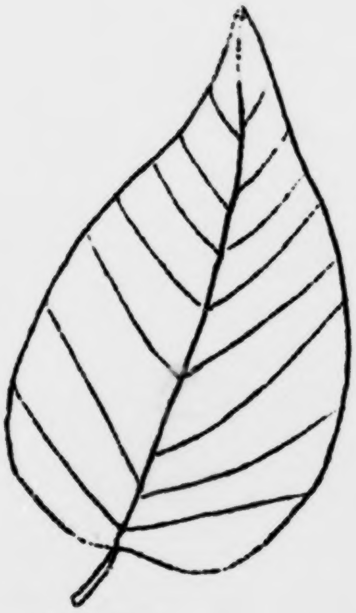
VENATION



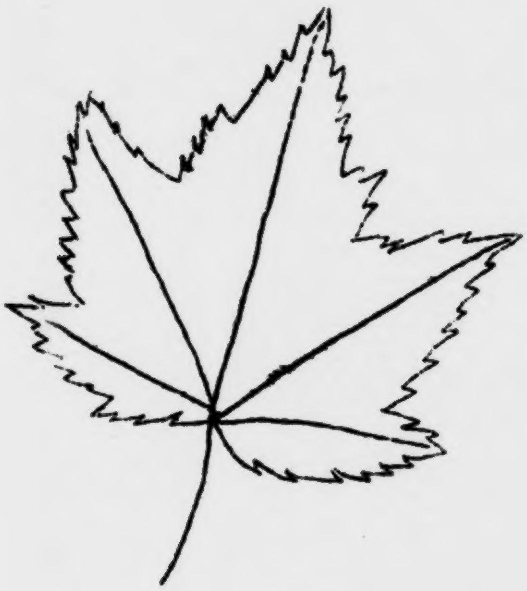
Parallel



Curved Pinnate



Pinnate



Palmate

LEAF KEY*

1. Leaves are needles or scale-like----go to 2
1. Leaves are broad and flat----go to 13

2. Leaves are needles----go to 3
2. Leaves are scale-like----go to 13

3. Needles are in bundles----go to 4
3. Needles are not in bundles----go to 9

4. Needles are in bundles of 5 or more----go to 5
4. Needles are in bundles of 2 or 3----go to 6

5. Needles are in tufts of more than 5----TAMARACK or LARCH
5. Needles are in bundles of 5----WHITE PINE

6. Needles are in bundles of three----PITCH PINE
6. Needles are in bundles of two----go to 7

7. Needles are thick and 1 to 1½ inches long----JACK PINE
7. Needles are flat, slightly twisted, 2 or 3 inches long----SCOTCH PINE
7. Needles are flexible, 4 to 6 inches long----go to 8

8. Sheaf around bundle is short----AUSTRIAN PINE
8. Sheaf around bundle is long----NORWAY (RED) PINE

9. Needles are plain, green on both sides----go to 10
9. Needles have white lines on underside----go to 11

10. Needles are stiff and sharp----SPRUCE
10. Needles are flexible and flattened----YEW

11. Needles are flat, sessile----BALSAM FIR
11. Needles are flat, have petioles----HEMLOCK

12. Some needles are flattened, some are sharp----JUNIPER (RED CEDAR)
12. All needles are flattened----ARBOR VITAE (WHITE CEDAR)

13. Leaves are arranged opposite on branches----go to 14
13. Leaves are arranged alternate on branches----go to 26

14. Leaves simple----go to 15
14. Leaves compound----go to 22

15. Leaves curved pinnate veined, margin smooth----FLOWERING DOGWOOD
15. Leaves palmate veined----go to 16

16. Margin entire, leaf very large----CATALPA
16. Margin lobed, fruit a samara (winged)----go to 17

17. Sinuses pointed----go to 18
17. Sinuses rounded----go to 19

---

*The directions for the use of a key in identification of leaves and the key which follows are reprinted from Science Skills by David Newton. This material is used with the permission of J. Weston Walch, Publisher.

18. Sinuses are deep----SILVER MAPLE
18. Sinuses are shallow----RED MAPLE

19. Drop of "milk" appears at end of petiole if broken----go to 20
19. No "drop" of milk appears if petiole broken----go to 21

20. Leaves are green in spring----NORWAY MAPLE
20. Leaves are deep purple in spring----SCHWEDLER MAPLE

21. Leaves are deep green, longer than wide----SUGAR MAPLE
21. Leaves are deep green, wider than long----BLACK MAPLE

22. Leaflets pinnately arranged----go to 23
22. Leaflets palmately arranged----go to 25

23. 3 to 5 irregularly shaped leaflets----BOX ELDER (COMPOUND LEAFED MAPLE)
23. 5 to 11 leaflets----go to 24

24. Leaflets are sessile----BLACK ASH
24. Leaflets have petioles----WHITE ASH

25. 5 leaflets to a leaf----OHIO BUCKEYE
25. 7 leaflets to a leaf----HORSE CHESTNUT

26. Leaves simple----go to 27
26. Leaves compound----go to 50

27. Margin entire, or nearly so----go to 28
27. Margin serrate----go to 29
27. Margin undulate, base of leaf oblique----WITCH HAZEL
27. Margin dentate----go to 45
27. Margin lobed----go to 46

28. Leaf heart-shaped, fruit a pod----RED BUD
28. Some leaves "mitten shaped," fruit a drupe----SASSAFRAS

29. Stems of twigs with thorns----HAWTHORN
29. Stems of twigs without thorns----go to 30

30. Base of leaf oblique----go to 31
30. Base of leaf symmetrical----go to 33

31. Leaf is wide or wider than long----BASSWOOD
31. Leaf 1 and one-half times as long as wide----go to 32

32. Teeth completely around margin----AMERICAN ELM
32. No teeth near base----HACKBERRY

33. Veins are straight and evenly spaced----go to 34
33. Veins are not straight and evenly spaced----go to 37

34. Bark of tree peels horizontally----go to 35
34. Bark does not peel horizontally, base of leaf is heart-shaped----IRONWOOD

35. Leaves in pairs----go to 36
35. Leaves single, base of leaf straight across, bark white----WHITE BIRCH

36. Bark is brown----BLACK BIRCH
36. Bark is bronze----YELLOW BIRCH

37. Leaves have pungent odor, there are lenticles in bark----go to 38
37. Leaves without odor, no lenticles in bark----go to 40

38. Leaf is long and tapering----go to 39
38. Leaf is obovate----CHOKE CHERRY

39. White dots on twigs----BLACK CHERRY
39. Brown dots on twigs----PIN CHERRY

40. Leaf linear----WILLOW
40. Leaf triangular----go to 41

41. Petiole flattened----go to 42
41. Petiole round----BALM OF GILEAD

42. Base of leaf straight across----go to 43
42. Base of leaf not straight across----go to 45

43. Leaf longer than wide----COTTONWOOD
43. Leaf wider than long----LOMBARDY POPLAR

44. Teeth very large----LARGETOOTH ASPEN
44. Teeth very tiny----QUAKING ASPEN

45. Leaf thin and shiny, smooth on both sides with one tooth for every vein----BEECH
45. Leaf large, teeth curved toward apex of leaf----CHESTNUT

46. Fruit not an acorn----go to 47
46. Fruit an acorn----go to 49

47. Leaf pinnately veined----go to 48
47. Leaf parallel veined, leaf fan-shaped, with two equal lobes----GINGKO

48. Leaf looks as though tip were cut off----TULIP TREE
48. Leaf very large and coarse, bark on tree peels naturally----SYCAMORE

49. Lobes bristle-pointed----BLACK OAK FAMILY
49. Lobes rounded----WHITE OAK FAMILY

50. Leaflets with entire margin----go to 51
50. Leaflets with serrate margin----go to 52

51. Leaves once compound, branches armed with short, sharp thorns----BLACK LOCUST
51. Leaves once or twice compound, branches with long thorns----HONEY LOCUST

52. Leaflets rounded with abrupt apex----MOUNTAIN ASH
52. Leaflets elongate----go to 53

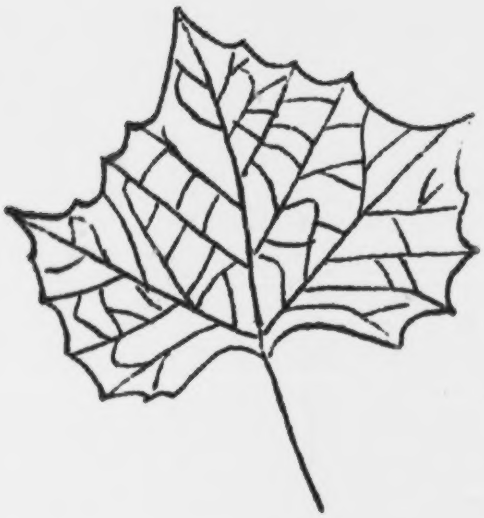
53. Leaves with 13 to 41 leaflets, leaflets with 1 or 2 coarse teeth at base----AILANTHUS
53. Leaves with 5 to 23 leaflets, leaflets complete serrate----go to 54

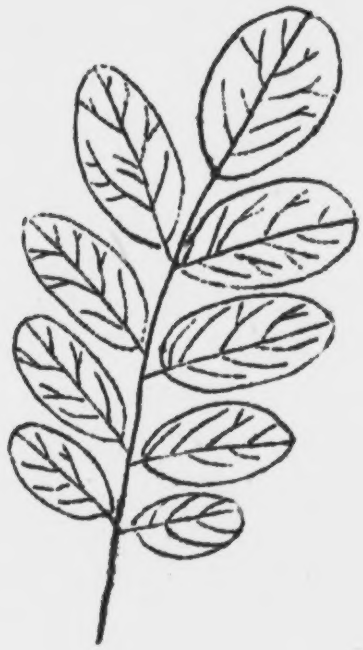
54. Leaves with 5 to 7 leaflets----go to 55
54. Leaves with 7 to 23 leaflets----go to 56

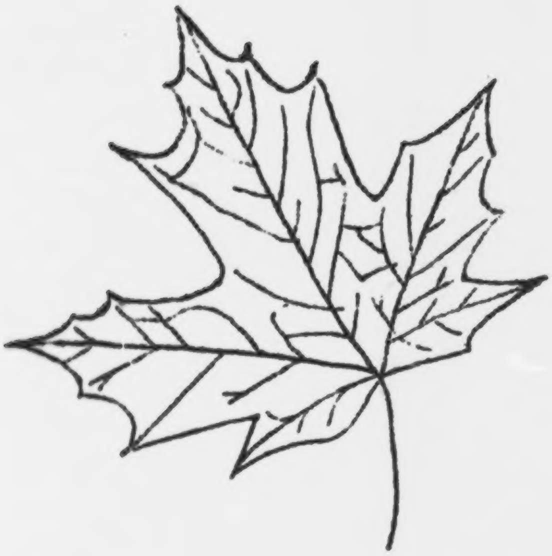
55. Leaflets smooth, bark separates in loose shaggy strips----SHAGBARK HICKORY
55. Leaflets downy beneath----BUTTERNUT

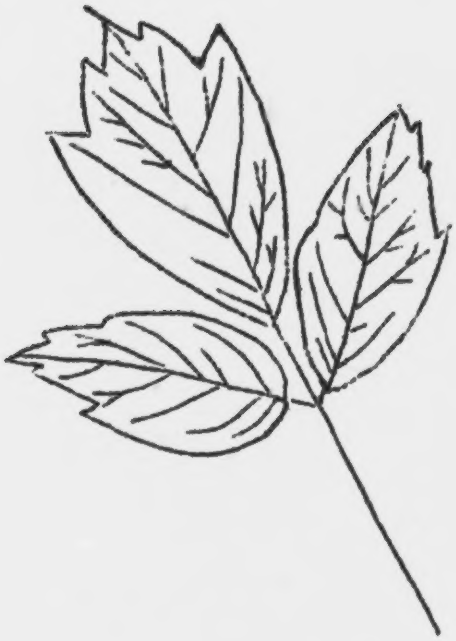
56. Brown pith in twigs----BUTTERNUT
56. Cream pith in twigs----BLACK WALNUT

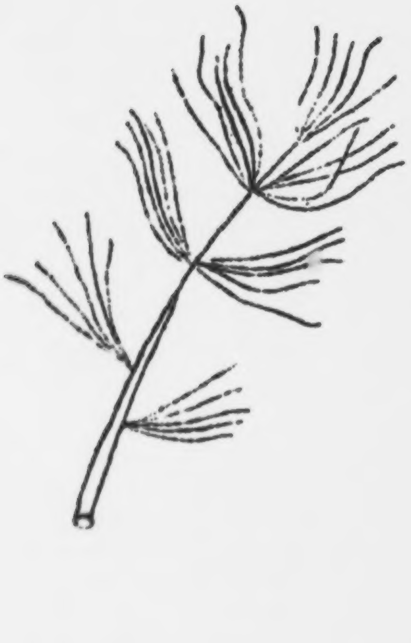
PICTURES OF LEAVES FOR IDENTIFICATION

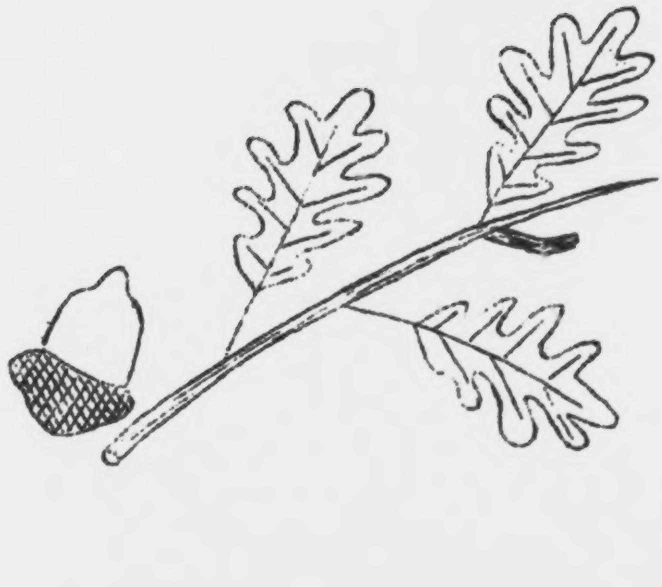












Idea of Quantification B.2.

Idea Bridge: The Relative Nature of Measurement

Most people think of units of measurement as things which have an existence of their own. Actually, all measurement is relative. Something is compared to something else. Ultimately we have developed a set of abstract standards to which we have come to compare things. These are our units of measurement.

Furthermore, the importance of specific units of measurement, and the importance of the actual measurements that we obtain by using them, are relative to the sizes of the things being measured, and to the size and importance of the problem for which we need the measurements.

How important is it that you know about the "50 cents" if (a) you have only $1.50 when you are ordering dinner at a restaurant? (b) if you have only $51.50 in your checking account at the bank when you wish to buy an article of clothing? (c) if you have $5,150.50 in your savings account when you wish to make a down payment on a house? (d) if a proposed expenditure by the company for which you work is $55,151.50? (e) if an inter-continental ballistics missile costs the federal government $5,151,151,151.50? Why?

LABORATORY EXPERIENCE B.2.a.

Measurement and You

Introduction:

You have used a foot ruler or a yardstick to measure things. You have measured the distance from your house to school by counting the number of blocks. You probably know the number of miles from your city to another city, although you have never measured the distance. What is measuring? How do we measure?

Materials and Equipment:

Sheets of typing paper

Scissors

Table

Book

Dime

Ruler (marks in inches, and fractions of inches to sixteenths)

Envelope

Collecting Data:

Cut a strip of paper the length of your hand and the width of two fingers. Give your strip a "made-up" name as a unit of measurement. Measure the length and width of a table with your strip. Estimate any fraction of the strip. Put the figures from the entire class for the length and width in a composite data chart (See example below) on the chalkboard. Why do the measurements vary? Are one set of measurements "right" and another "wrong"? Why? What would we have to do for everyone to have the same measurements? Would they all then be "right"? Why? Would using a foot ruler make them "right"? Why or why not?

Composite Data Table

Name of student	Name of measuring unit	Length of table	Width of table

Now measure the length and width of a book. What could you do to your strip of paper so you could measure without estimating fractions of the strip? Give a name to each smaller unit of measurement produced in this way. Record the length and width of your book in the new smaller units. Measure the table again. Record your measurements on a composite data chart in terms of the smaller unit. What advantage does using a smaller unit of measurement have? What disadvantage?

Now measure the width and thickness of a dime. Do this without further instructions. Record the data on a composite data chart. Whose measurements are "right"? What advantage is it to have smaller units when you measure a dime? What disadvantage? When might you want still smaller units?

What is measurement? What advantage would it be if all of us used the same length of paper as the unit of measurement? What are some of the measuring units formerly used by people? What is the origin of the units? Is there another system? What is it?

Making a Hypothesis:

What do you think is the relationship between the size of the object being measured and the size of the unit of measurement? State a hypothesis expressing this relationship.

Testing Your Hypothesis:

By trial and error, find a way of folding a sheet of typing paper so that it will exactly fit into an envelop with gentle forcing. Examine a ruler. Locate the marks that indicate whole inches. These are numbered. Within each locate the marks that measure half-inches, quarter-inches, eighth-inches, and sixteenth-inches. Measure the external size of the envelop across its narrowest dimension. Now, measure the corresponding dimension of the folded paper that you fitted into it. Press the envelop and folded paper as flat as you can on the table when you make the measurements. Do you find a small difference in this measurement? Can you measure the difference? How much difference is there?

Now work in a group of three students. Each person should make his own measurements, but should feel free to ask help from the others whenever cooperation is necessary.

Measure your own height. Measure to the nearest quarter-inch. Why?

Measure the height of your team mates. Measure to the nearest quarter-inch. Why?

Measure the classroom-both length and width. Measure to the nearest half-inch. Why? Why not to the nearest quarter-inch?

Measure your schoolground or a selected portion of it. Measure it to the nearest inch. Why not to the nearest half-inch or quarter-inch? Why do you eliminate the smaller fractions of inches progressively as you go along?

Now compare all of your measurements with those of your two teammates. How much difference do you find? Who was "right?"

Repeat all of your measurements. To what extent do your measurements the second time agree with those you made the first time? How much do they disagree? Why? How about agreement with your teammates?

Could you have limited your measurement to larger fractions of inches or full inches, or even larger units? Would you have achieved agreement with your teammates then? Would you have achieved better agreement between your first and second measurements? Why? At what point would you have needed to stop in each case to achieve agreement? Would this have been a more meaningful limit? Why?

Follow-Up:

All measurements are relative. What are they relative to? When are measurements useful? When are they absolutely necessary? In what kinds of human situations are they useless? What kinds of things cannot be measured? How about the "funniness of a joke?" How about happiness? What about the beauty of a painting? The "goodness" of a person?

LABORATORY EXPERIENCE B.2.b.

Precision

Introduction:

You have found that measurement is relative. It is relative to the unit of measurement which you use, whether it is something that you devise, or is a standard unit of measurement such as the inch, foot, pint, quart, ounce, or pound.

It is more convenient to use standard units because they enable everyone with whom you are communicating to know what you mean. If a recipe tells a cook to use "five blings" of flour, she would first have to find out how much a "bling" is, but if it says "five cups", she can use any standard measuring cup. Is it possible for her to get exactly five cups? Why or why not?

If a board needed to be 18 inches long, a ruler would enable a carpenter to cut the board to the required length; directions that specified "18 wastles," however, would cause him difficulty. But could he cut a board to exactly 18 inches? If his ruler had only inch measurements he could cut to the nearest inch. That would meet the specifications and should be close enough. But what if he needed a fraction of an inch? Could he estimate it? A half inch? A fourth inch? An eighth inch? Would it depend on how he intended to use the board? Would his estimate be close enough? If he had a ruler that had half-inch units of measurement, he could measure and cut to the nearest half-inch. Would that be closer than to the nearest inch? Are there times when a carpenter must have a means of measuring to the nearest fourth inch; to the nearest eighth inch? When? Why?

Materials and Equipment:

Accompanying page with rulers outlined

Ruler calibrated to sixteenth inches

Collecting Data:

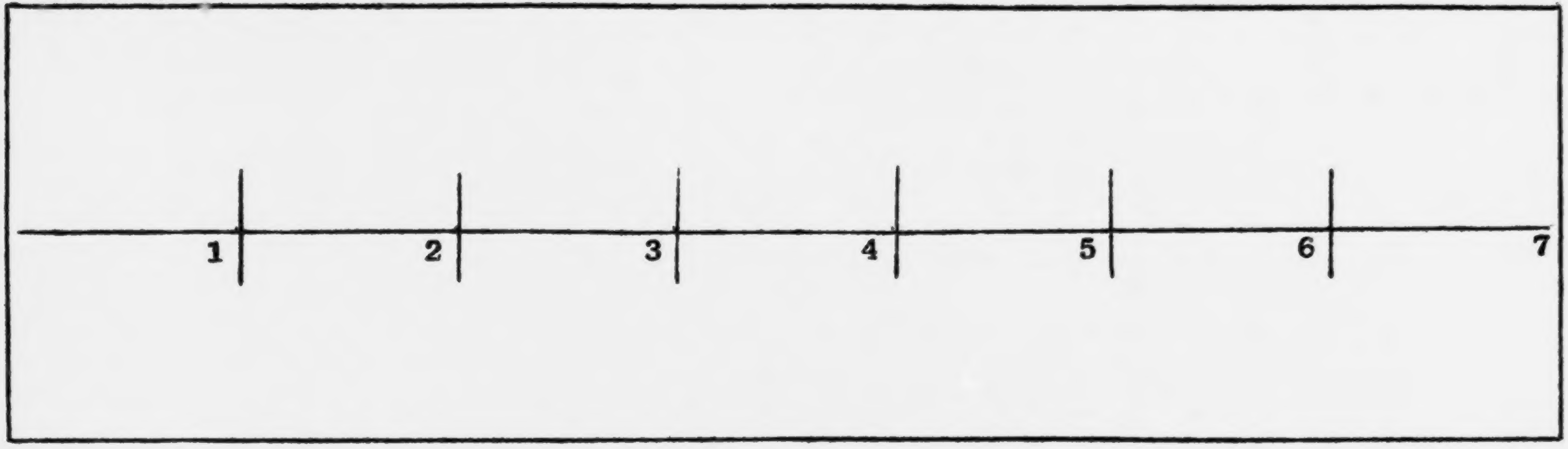
Cut out Ruler No. 1 on the accompanying page, and fold it as directed. Measure the length of line segment $\overline{AB}$ on the following page to the nearest inch. Do not use fractions. Record your answer on the Data Chart. How much could your error be? Is it agreed that you could not be more than one-half inch off? Why? Record this as your absolute error. (This is your greatest possible error.) Now, using Ruler No. 1, measure and record the length of line segments $\overline{MN}$, $\overline{ST}$, and $\overline{JK}$.

Cut out and fold Ruler No. 2. What is the smallest fractional unit on this ruler? Measure line segments AB, $\overline{MN}$, $\overline{ST}$, $\overline{JK}$. How large could your error be? Why? Record the absolute error in each case.

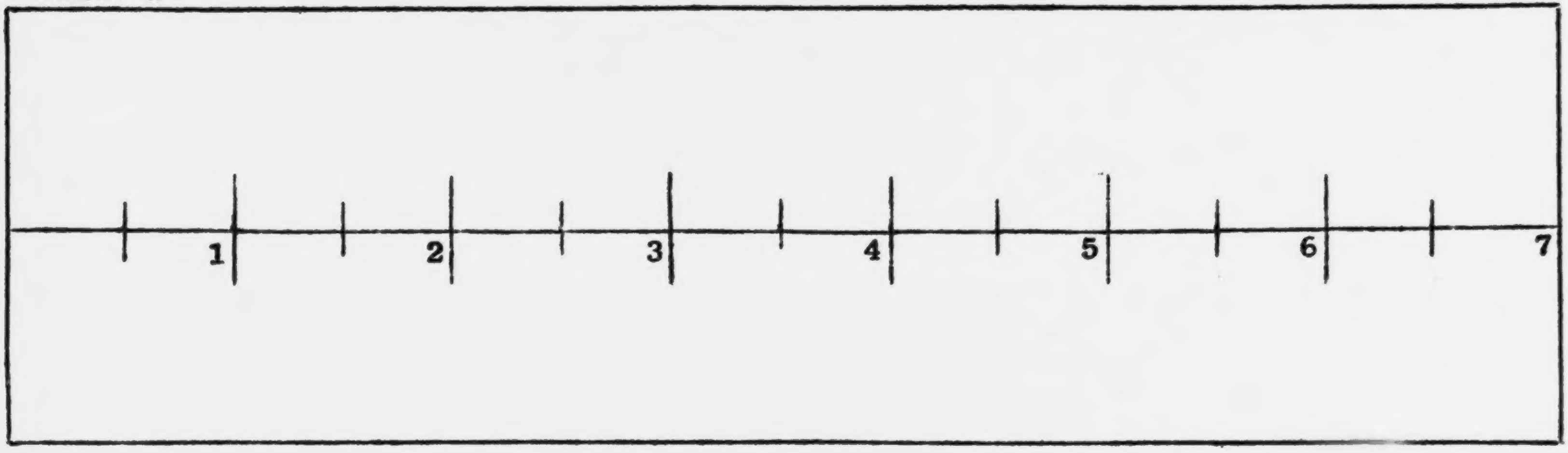
Repeat with Ruler No. 3 and Ruler No. 4. What happens to the size of the absolute error if the fractional units on the rulers get smaller? The smaller the absolute error, the greater the precision.

PAPER RULERS

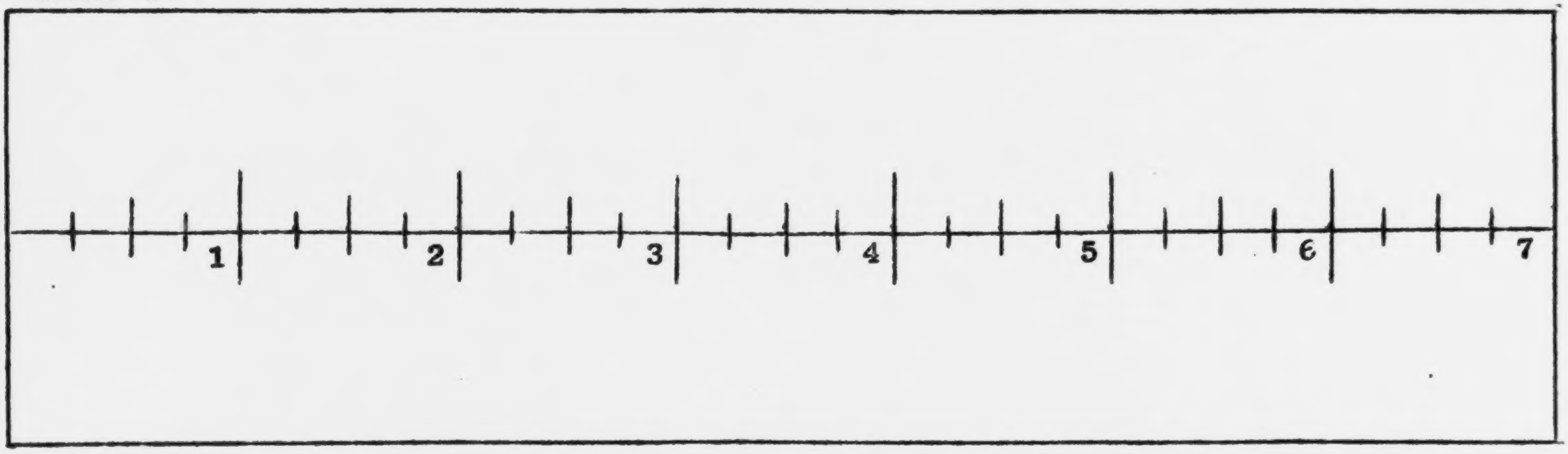
Ruler #1



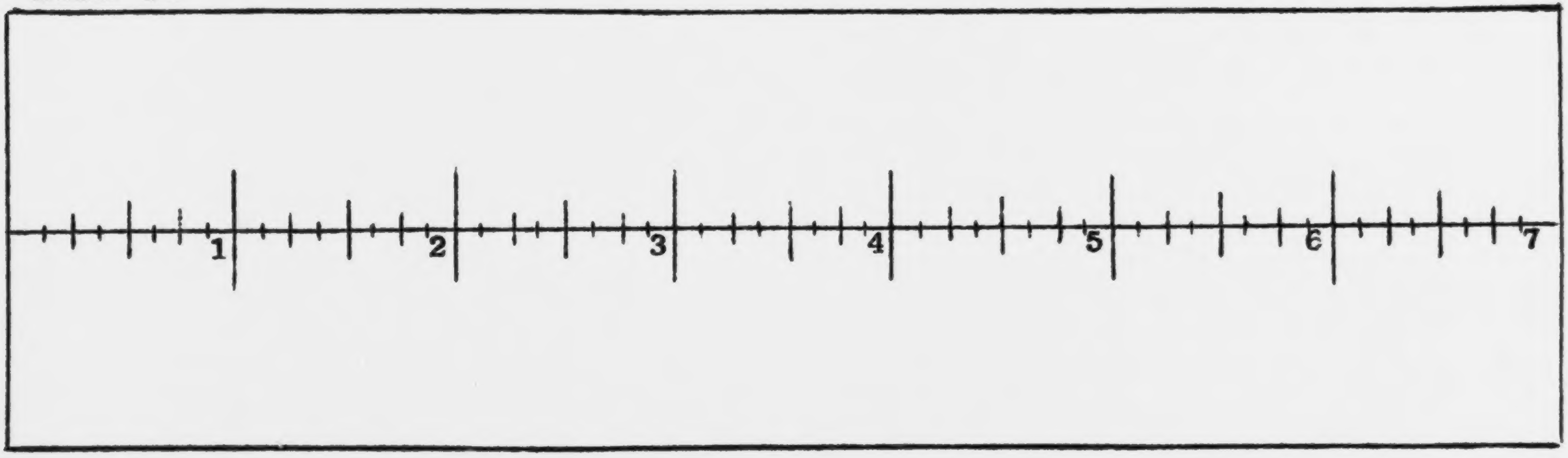
Ruler #2

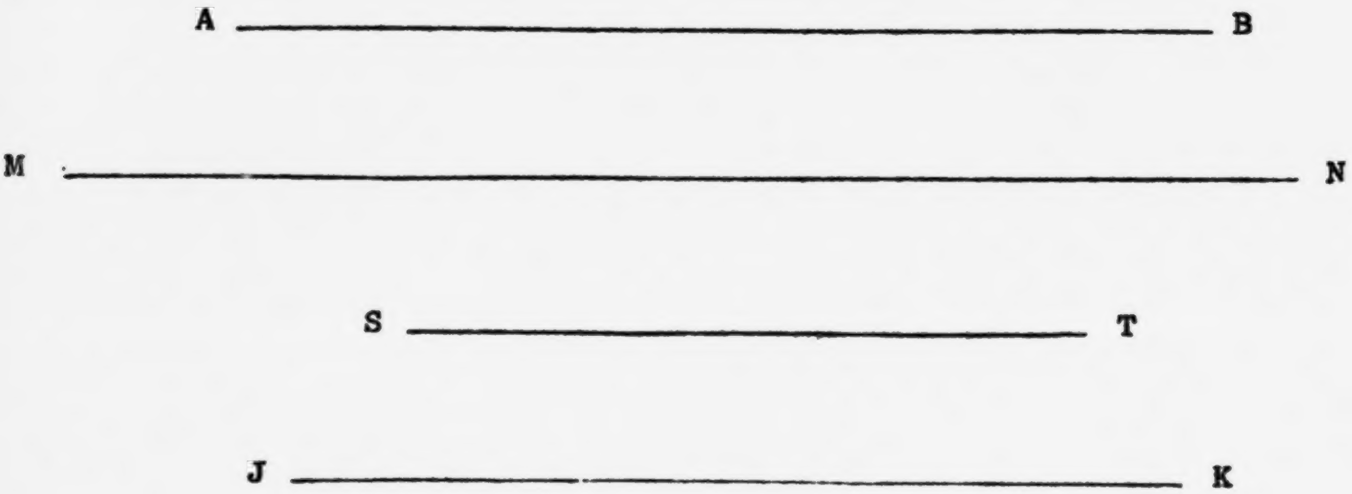


Ruler #3



Ruler #4





DATA CHART

	Ruler 1	Ruler 2	Ruler 3	Ruler 4	Ruler 5
Absolute Error					
Length of $\overline{AB}$					
Length of $\overline{MN}$					
Length of $\overline{ST}$					
Length of $\overline{JK}$					

Formulating a Hypothesis:

Make a statement relating degree of precision to the size of the unit or fractional unit that you are using.

Testing Your Hypothesis:

How have you *already* tested your hypothesis? Test it further by using a ruler marked with one-sixteenth inch fractional units (*Ruler No. 5*) to measure line segments $\overline{AB}$, $\overline{MN}$, $\overline{ST}$ and $\overline{JR}$. Record all data on the *Data Chart*. Compare with the results obtained by using the other rulers.

Could you test your hypothesis further by setting up a laboratory experience using *liquid measures* such as quart, pint, cup, tablespoon, and teaspoon? Will every answer be an *approximation* of the actual contents? Could you test your hypothesis by using units of *weight*? How could you do so?

Follow-Up:

When is precision of measurement of greatest importance? When would you *not* need a great deal of precision?

LABORATORY EXPERIENCE B.2.c.

Accuracy

Introduction:

Many people use the work accurate when they mean precise. A scientist, however, never uses these terms interchangeably. Accuracy has a meaning different from precision. Precision is related to absolute error (greatest possible error). This is determined by the size of the unit or fractional unit of measurement being used. Let us find out what determines the accuracy of a measurement.

Materials and Equipment:

Paper rulers used in Laboratory Experience B.2.b.

Collecting Data:

Use the designated rulers from the earlier investigation (B.2.b.) to measure the line segments on the accompanying page. Record the length and absolute (greatest possible) error in each case on Data Chart No. 1 on the accompanying page. The first one is done for you.

If you distribute the absolute error evenly among the measurement units, you have the amount of error for each unit. This is called the relative error. To find the relative error, divide the absolute error by the measurement:

$$5\overline{)\,.5}\quad \underline{n}\quad 1/2 \div 5 = 1/2 \text{ X } 1/5 = 1/10$$

Record this relative error on Data Chart No. 1. Compute the relative error for each measurement on the chart.

Formulating a Hypothesis:

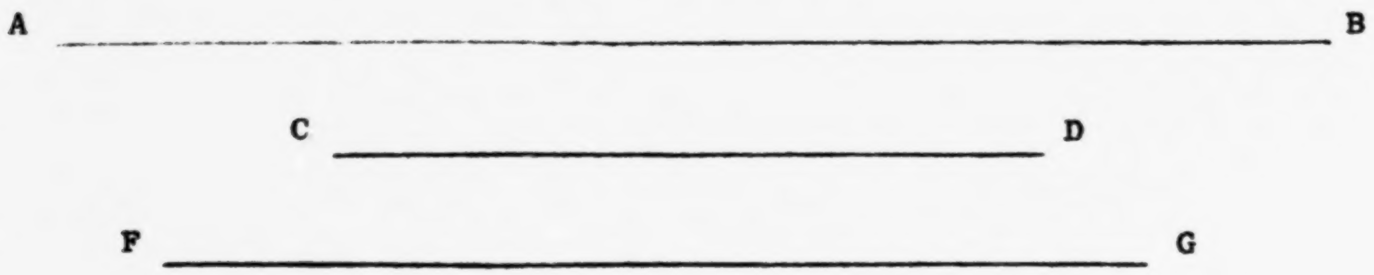
Write a statement that relates accuracy and relative error just as you related precision and absolute error in Laboratory Experience B.2.b.

Testing Your Hypothesis:

Complete Data Chart No. 2. Which of the measurements is the most precise? Which is the most accurate? Why?

Follow-Up:

When is precision more important than accuracy? When is precision rather unimportant? Is accuracy ever unimportant? Why?



DATA CHART NO. 1

Ruler to Use	Line Segment	Measurement of the Line Segment	Absolute Error	Relative Error
No. 1	AB	5	.5 or ½	
No. 1	CD			
No. 2	AB			
No. 3	FG			
No. 4	CD			
No. 4	FG			

DATA CHART NO. 2

Smallest Unit	Measurement	Absolute Error	Relative Error
1 inch	20 inches		
1 inch	10 inches		
½ inch	5 inches		
¼ inch	2 inches		
¼ inch	10 inches		

LABORATORY EXPERIENCE B.2.d.

A Way to Measure Length

Introduction:

You have devised your own linear system, and found that it had certain disadvantages. You have found out about precision and accuracy when using a ruler calibrated (marked off evenly) in units and sub-units of the English system of measurement which is in everyday use. Now we are ready to understand the system of linear measurement used by scientists.

Materials and Equipment:

Meter stick

Knowledge of the monetary units and sub-units
used in the United States of America.

Collecting Data:

Lay a meter stick in front of you on the table. Compare it with units and sub-units of American money. In money a dollar is divided into ten equal parts called dimes. A meter*is likewise divided into ten equal parts called decimeters. Find a decimeter on the meter stick. Ten dimes are equal to one dollar; ten decimeters are equal to one meter. Deci and dime both mean one-tenth.

Measure line segments $\overline{AB}$ and $\overline{CD}$ on the accompanying page to the nearest decimeter. A decimeter may be written as "decimeter" or ".10 meter." Likewise a dime may be written as "1 dime" or ".10 dollar." Record your measurements on the Data Chart as decimeters, and as decimal parts of a meter.

In money a dollar is divided into 100 equal parts called cents. A meter is likewise divided into 100 equal parts called centimeters. Find a centimeter on the meter stick. Just as there are ten cents in a dime and 100 cents in a dollar, there are ten centimeters in a decimeter, and 100 centimeters in a meter. Just as a cent can be written "1 cent" or ".1 dime" or ".01 dollar," a centimeter can be written as "1 centimeter" or ".1 decimeter" or ".01 meter."

What are some other words that have "cent-" in them as a syllable, and mean "one hundred?"

Measure line segments $\overline{MN}$ and $\overline{OP}$ on the accompanying page and record the measurements in centimeters, in decimeters, and in meters on the Data Chart, using fractional units as necessary.

If you had to measure with precission the thickness of a dime, you would need a smaller unit than a centimeter. What fractional unit could you use? In money a tenth of a cent is called a mill. There is no coin called a mill, but mills are used as units of calculation in figuring taxes.

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* A meter is a very close approximation of one ten-millionth of the distance from the north pole to the equator.

Have you ever read about them or heard adults talk about them? A mill may be written as "1 mill", or ".1 cent" or ".01 dime" or ".001 dollar". There are 10 mills in a cent, 100 mills in a dime, and 1000 mills in a dollar.

A meter stick is divided into 1000 units called millimeters. Ten millimeters equal one centimeter, 100 millimeters equal one decimeter and 1000 millimeters equal one meter. A millimeter may be written as "1 millimeter," or ".1 centimeter", or ".01 decimeter", or ".001 meter."

How would you measure the thickness of a dime? What are some other words that have "mill-" in them as a syllable, and mean "one thousand?"

Measure line segments $\overline{RS}$ and $\overline{TU}$, and record the measurements on the Data Chart in millimeters, centimeters, decimeters and meters, using fractional units as necessary.

Follow-Up:

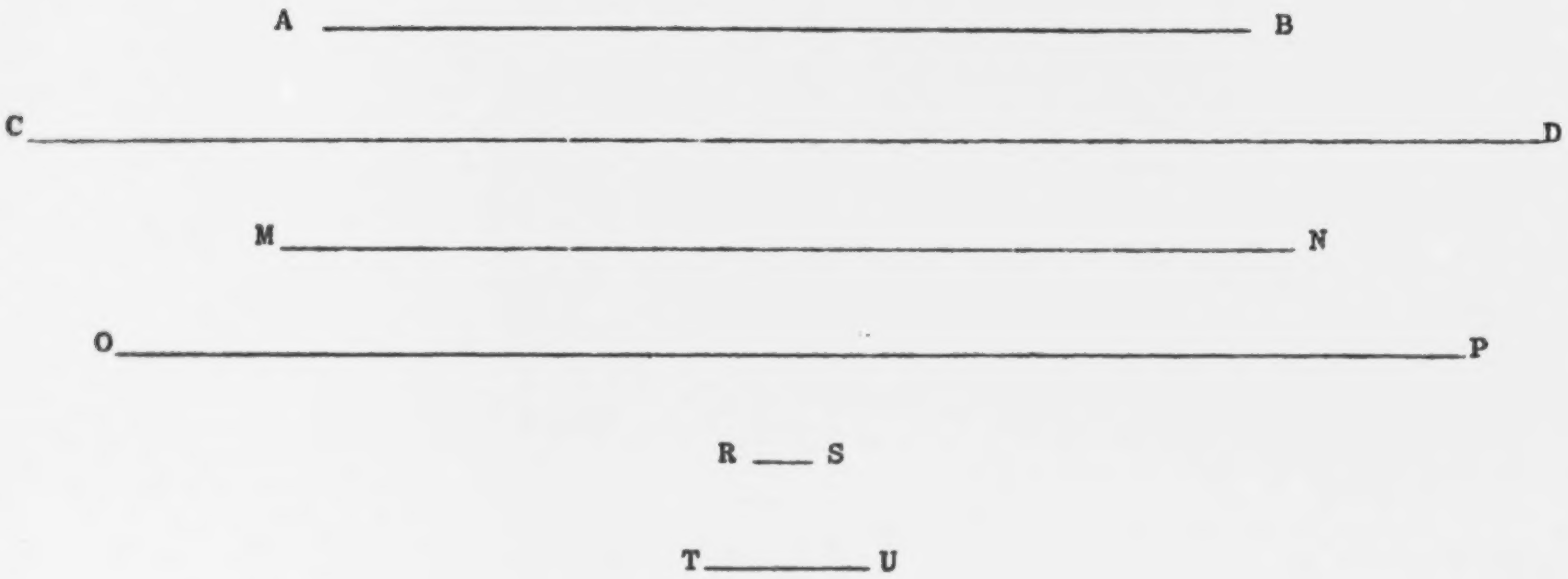
Measure your book, your table or desk, the room, and other readily accessible dimensions. Record your answers in millimeters, centimeters, decimeters and meters, using fractional units as necessary.

The larger units in the metric system are decameter, hectameter, and kilometer. Find out what each one means. Which one is most frequently used? How does it compare with a mile? Figure out various distances which you know in terms of miles (such as to other towns or cities) using this unit. Do you know anyone who drives an automobile with a speedometer indicating speed per hour in terms of this unit rather than miles per hour? What is the country in which the car was manufactured? What kind of surprise would you experience if you looked at such a speedometer while the car was traveling?

What is the absolute error for each linear metric unit? Which unit would give the greatest precision?

Learn the abbreviations for the common metric linear units.

Do other countries use decimal units for their monetary system? What ones do not? What units do they use?



DATA CHART

Unit Used in Measuring	Line Segment	Measurement			
		Millimeters	Centimeters	Decimeters	Meters
Decimeter	$\overline{AB}$	xxx	xxx		
Decimeter	$\overline{CD}$	xxx	xxx		
Centimeter	$\overline{MN}$	xxx			
Centimeter	$\overline{OP}$	xxx			
Millimeter	$\overline{RS}$				
Millimeter	$\overline{TU}$				

LABORATORY EXPERIENCE B.2.e.

A Way to Measure Capacity and Weight

Introduction:

Your mathematics book probably contains one or more pages of tables showing measures of length, liquid capacity, dry capacity, and weight. In the metric system you need only two new root words and the same prefixes you used in linear measurements. The relationships are the same.

Materials and Equipment:

Volumetric flask, calibrated in milliliters

Graduated cylinder, calibrated in cubic centimeters

Balance, with weights in metric units

Collecting Data:

The unit of capacity in the metric system is the liter. Re-copy and complete the following table:

1/1000 of a liter = 1 (?)
1/100 of a liter = 1 (?)
1/10 of a liter = 1 (?)
10 liters = 1 (?)
100 liters = 1 (?)
1000 liters = 1 (?)

The unit of weight in the metric system is the gram. Re-copy and complete the following table:

1/1000 of a gram = 1 (?)
1/100 of a gram = 1 (?)
1/10 of a gram = 1 (?)
10 grams = 1 (?)
100 grams = 1 (?)
1000 grams = 1 (?)

There is a definite relationship between the linear unit, the capacity unit, and the weight unit of the metric system.

Put 100 milliliters of water into a volumetric flask. Carefully pour the water into a graduated cylinder. Notice that the surface of the water forms a curve. This is called a miniscus. What causes it? Read the liquid level at the lower edge of the miniscus. How many cubic centimeters of water do you have? What is the relationship of one milliliter and one cubic centimeter?

Try different amounts of water in the volumetric flask and in the graduated cylinder? What is the basis for the relationship of the linear unit of measurement and the capacity unit in the metric system?

Carefully weigh an empty graduated cylinder on a balance, using metric units. Pour 100 milliliters of water from the volumetric flask into the graduated cylinder. Weigh the cylinder and the water. How can you determine the weight of the water? Does there appear to be a relationship between the metric unit of capacity and the metric unit of weight? What is the relationship? How are both related to the linear unit of measurement?

Try several different amounts of water to verify your findings. Any slight discrepancies you find are probably due to the temperature of the water and/or impurities in the water. What kind of water should you use, and what temperature should it be to obtain more precise relationships?

Follow-Up:

Work the following (on a separate page) to see if you understand the relationships in the metric system.

1000 cubic centimeters = (?) liter(s)
1 cubic decimeter = (?) liter(s)
1 liter (of water) = (?) liter(s)
1/100 gram = (?)
1/1000 gram = (?)

Add others. What is a megaliter? A microsecond? A namosecond? A gigameter? A light year, expressed in metric linear units?

Learn the abbreviations for the commonly used metric units of capacity and weight.

Are the common units used for measuring time: second, minute, hour, day, week, month, English units, metric units, or common to both? Are they based on the decimal system? Why or why not? What about century? Millenium?

What about the Centigrade scale for measuring temperature? What is the basis for it? Compare it with the Fahrenheit scale.

LABORATORY EXPERIENCE B.2.f.

Measurement of Time

Introduction:

Many years ago a science fiction writer, Edgar Rice Burroughs, wrote a book called "At the Earth's Core." In this story, he imagined that the earth was a hollow ball, with another world occupying the inner surface of the ball. This inner world, of course, had a concave surface, instead of the convex surface of the world we know on the outside.

The inner, concave world was lighted by a "sun" located in the center of the hollow sphere. This sun always stood still. Therefore, there was no day or night. It was always "noon" to the people who lived on the inner surface, with the sun directly overhead. The climate was humid and tropical, and there were no seasons.

Although people were born, lived, and died, they had no way to measure time, and therefore had no understanding of its duration. Any moment seemed to last forever. Psychological time (time as it seems to us) does not necessarily correspond to actual physical time (time as it is measured by a clock). Have you ever experienced a few seconds or a minute that seemed like a much longer period? Likewise, biological time, as indicated by the aging of individual people, does not always correspond to physical time. Have you ever known people 60 or 70 years old, who seemed much younger?

Unlike the people who lived in Edgar Rice Burroughs' imaginary inner world, we have various natural cycles which we use to measure time. We speak of days, months, years, generations. All of these are based on cycles: alternating day and night, the phases of the moon, the changes of the seasons, and the human life cycle of birth, growth, maturity, aging and finally death. We also use other time measurements: minutes, hours, weeks, centuries, millenia. These are based on arbitrary time intervals rather than natural cycles. Can you find any reason for them?

Materials and Equipment:

Source of information(almanac or daily newspaper giving weather and astronomical data) for time of sunrise and sunset.

Calendar or almanac showing phases of the moon

Daily weather maps (newspaper or other source)

Collecting Data:

When is the longest day in the year? The shortest day? Are the dates always the same? Are the summer days longer and the winter days shorter as you go to more northern latitudes? Why? What about southern latitudes? How does this affect the length of the longest and shortest days in the area where you live?

Locate a source of information that gives the time of sunrise and sunset each day. Calculate day-length for a period of successive days. How much does each day increase in length following the shortest day in the year, or decrease following the longest day in the year? Is the amount of increase or decrease the same for each day? Does it occur at the beginning or end of the day? Or is it divided evenly between the beginning and the end? Is it always the same, or does it occur sometimes one way and sometimes another? Can you state a generalization concerning the changes in day length?

A lunar cycle is approximately 28 days long. What are the phases of the moon? Look them up on a calendar. Follow them by observing the moon on clear nights for a month. How many lunar cycles are there in a year? How does this compare with the number of months? How was the number of days in each month determined?

Study daily weather maps each day for a month. Observe the weather each day during the same period of time. Does the weather follow the map? To what extent are weather forecasts accurate? How are they made? Watch for monthly long-range weather forecasts in your local paper. How accurate are they? How are they made? How has weather forecasting become more efficient as a result of the orbiting of weather satellites?

Are there cycles of weather? How reliable are old weather proverbs such as, "If it rains on Easter Sunday, it will rain for seven Sundays after?" Do frontal systems, as shown on weather maps, bringing storms and rainfall, tend to pass across the continental United States about once a week? Try this out as a hypothesis. Study a series of daily weather maps to test it. Can you think of any reason why weather cycles have not been used to measure the passage of time?

How long is a human generation (from birth to reproduction)? How many human generations, defined in this way, are there in a century? There is also a human memory generation. How old is the oldest person you know? When was this person born? If this person remembers a person of similar age who lived when he or she was a child, when would that person have been born? How many such memory generations have there been since the Civil War? Since the Revolutionary War? Have human generations ever been used to measure the passage of time? Which kind of generation do we mean when we say that something happened "a generation ago?"

Follow-Up:

A number of physiological cycles take place in the bodies of humans and other animals. How many of these can you think of? What about the heart beat? Look up a description of heart action. What is an electrocardiogram? Are we using the cycle of heart action to measure time when we say that the vice-president of the United States is "only a heart beat away from the presidency?"

What about body temperature? Is it always 98.6 degrees Fahrenheit when a person is healthy, or does it change during each 24 hour period? Is there a cycle? Find out about as many other physiological cycles as you can. Could you measure the passage of time with them? Why are they not used in this way?

LABORATORY EXPERIENCE B.2.g.

Measurement Is Dependent on Physical State

Introduction:

In this laboratory experience you will see that a quantity of material does not always remain the same size or volume. When the conditions under which it exists change, it undergoes resultant changes. You will see that some measurements are relative, being dependent on the physical condition of the materials being measured. Science is dynamic, and measurement is a concept for dealing with dynamic relationships as well as static ones.

Margin of error is related to the precision with which you are able to measure. In this experience you will see the importance of checking results and replicating procedures. The reliability of science depends on the repeatability of scientific experiences, within the range of a reasonable margin of error.

Many aerosol devices are on the market: insecticides, dessert toppings, deodorizers, shaving creams and others. In all of them, a liquid and a gas are mixed and held under pressure. Upon release of pressure, the gas escapes, carrying the liquid with it in the form of mist or foam. Shaking may be necessary to achieve maximum mixture, prior to releasing the gas. In aerosol instant shaving cream, a liquid soap is mixed with a gas under pressure.

Materials and Equipment:

Can of instant shaving cream

Wide mouth canning jars of the same kind and size, with tops

Graduate cylinder, 100 cc. capacity

Laboratory balance

Means for removing top from can

Masking tape

Collecting Data:

Students should work in pairs or small groups.

First laboratory period

1. Weigh the can of unopened instant shaving cream.

2. Weigh the empty jars with their tops.

3. Spray the contents of the can into the jars, filling as many as necessary. As you fill a jar, you may need to stir the contents occasionally to eliminate large air spaces.

4. Mark each jar with tape at the level attained by the foam.

5. Weigh the jars containing the foam.

6. Calculate the weight of the foam by subtracting the weight of the empty jars and tops.

7. Weigh the empty can, and calculate the weight of its contents by subtraction. Does the weight of the contents of the can correspond to the weight of the foam in the jars? Try to account for any differences that you find. Is the difference within a reasonable margin of error?

8. Screw the tops on the jars, and allow them to stand for one week.

Second laboratory period.

1. Note that a layer of liquid is now separated from the foam at the bottom of each jar. Examine the foam and see if it has changed in appearance or texture? If so, in what way? What do you think has caused the separation? What do you think was the physical state of the material in the can? What was the relation of the physical state of the original material to pressure?

2. Weigh the graduate cylinder which you will use in the next operation.

3. Pour the liquid from all of the jars into the graduate cylinder. You will find that you can pour the liquid out from under the foam along one side of the jar. If you do this slowly and carefully, the foam will not be disturbed, and very little of it will be carried off with the liquid.

4. What is the volume of the liquid?

5. Weigh the graduate cylinder containing the liquid.

6. Determine the weight of the liquid by subtraction.

7. Weigh the jars containing the remaining foam. Be sure to weigh the tops with them. Determine the weight of the remaining foam by subtraction.

8. Add the weight of the remaining foam to the weight of the liquid. How does the total compare with the weight of the original foam? With the weight of the contents of the original can? Are the differences within a reasonable margin of error?

9. Do you think any of the liquid has remained in the foam? Why? How much of the liquid in terms of volume do you estimate has remained in the foam? What total volume of liquid do you estimate is represented by the liquid which is separated out from the foam, plus that which is still contained in it?

10. Wash all foam out of the jars, and fill them with water up to the level of the original foam. Measure this volume of water, using the graduate cylinder.

11. Remove the top from the empty shaving cream can. Wash it out. Fill it with water, and measure this volume of water, using the graduate cylinder.

12. How much greater than the volume of the can is the volume that was filled with shaving cream in the jars? How much of the volume of the can was occupied by the total volume of liquid estimated in step 9? How can you determine the approximate volume of gas that was also contained in the can? How precise do you think your approximation is? Why? How much of the space in the can did this gas occupy? Assuming that your determinations up to this point have been reasonably accurate, how many times normal was the pressure under which the gas was held in the can?

13. Check the accuracy of your results, either by replicating (repeating) the experience, or by comparing your results with those of one or more other pairs or teams, who have used the same methods and kinds of material. Was your margin of error, in relation to the replicated experience, within a reasonable range of expectation? Try to explain any differences that you find.

Follow-Up:

What is specific gravity? How can you determine the approximate specific gravity of the liquid which separated out of the instant shaving cream? What is it? What does this indicate as to the solvent that was used to dissolve the soap?

What is the relationship of the three physical states of matter: solid, liquid and gas, to one another? Think of as many common examples of each state as you can. What examples of change from one state to another can you name?

What are the general relationships between pressure, temperature, volume, and physical state? How can these relationships be expressed mathematically? What are the gas laws?

B.3. Idea of Model Making

Idea Bridge: "Making and Using Models"

Have you ever built a model car or model airplane? In what ways were your models like real cars and airplanes? In what ways were they different? Why did you make your models? Do manufacturers of automobiles ever make models? What function would a model serve in the making of automobiles? What is a "mock-up?" How does a "mock-up" differ from most models? Why are "mock-ups" made?

In the classroom or laboratory, there are physical models of many things. A globe is a model of the earth. A map is a model of a part or all of the surface of the earth. Maps are usually two-dimensional models, although there are raised relief maps that are three-dimensional. A globe is a three-dimensional model. What other models are there in the classroom or the laboratory? Scientists use physical models to help them "picture" things that are so small that they cannot be seen with the unaided eye, nor in some cases even with a microscope. Scientists also make physical models of things that are too large to be brought into the laboratory, or in some cases too large even to be viewed as a whole.

Scientists also set up mathematical models. For example, the equation "2 + 2 = 4" is a model for putting two objects with two more objects, making a total of four objects.

Scientists also use mental models. They picture in their minds how an object looks, then they picture what it would look like if----; what it will look like when----; et cetera.

The necessity for making and using models, physical, mathematical, and mental, is based on an important scientific idea that is used in all fields of science. This idea is the generalized concept of a model.

LABORATORY EXPERIENCE B.3.a.

Making a Physical Model of an Atom

Introduction:

No one has ever seen an atom, yet atoms have been known for over 2,000 years. The ancient Greeks believed matter was composed of tiny particles that were incapable of division into smaller particles. They gave these tiny particles the name "atom," from the Greek word meaning "uncuttable." Since the late 1800's scientists have learned more and more about atoms. We know now that they are not "uncuttable", but are composed of many still tinier particles. We have also learned a great deal about their structure and properties.

Materials and Equipment:

Paper and pencil
Fine wire (soft and bendable)
Styrofoam balls, or breakfast cereal such as Cheerios, made in the form of tiny "O's"

Collecting Data:

Read in a science book about atoms and the sub-atomic particles: protons, neutrons, and electrons. Find out about the electrical charge of an atom, and the electrical charges of the sub-atomic particles of which it is composed. Read about the nucleus and the shells, and the arrangement of the particles in them. Find out how to tell from a List of Elements or from a chart of the Periodic Tables of Elements how many protons an atom of any particular element has. How can you tell how many electrons it has? How many neutrons? Find out how many electrons can be put in each shell. What is meant by a stable octet? Are the electrons in the shells standing still or are they in motion? Why does this make it difficult to describe an atom or picture it?

How could you most easily explain the structure of an atom to someone who knew nothing about one? You certainly could not show anyone a real atom. What could you do instead? How would you go about getting your idea across?

Hypothesis:

It should be possible for you to make and use a model to adequately explain the structure of an atom, even though all of the characteristics of an atom could not be represented even in this way.

Testing Your Hypothesis:

Try to make a schematic (two-dimensional) model of an oxygen atom. What is the structure of an oxygen atom? How many protons? Electrons? Neutrons? How are they arranged? Use little circles of varying sizes to represent protons, electrons, and neutrons. Decide upon a method for showing electrical charges. How can you show the nucleus and the shells with the sub-atomic particles in them?

Look up the composition of a sodium atom, and try to make a schematic model of it. This time use some method of representation other than circles for showing the particles.

Now try to make a three-dimensional model of a carbon atom. First look up the composition of a carbon atom. Use little "O's" from breakfast cereal (such as Cheerios), or tiny styrofoam balls, to represent the sub-atomic particles. Hold the "O's" or "balls" in place with fine, soft wire.

How are your models unlike real atoms? How are they like real atoms? What advantage does a model have over a word description? What advantage does a three-dimensional model have over a two-dimensional model? Why?

Follow-Up:

Find out what is shown by an electron dot diagram (electronic symbol) such as :Ö: . How is such a diagram used?

Find out how subscripts and superscripts are used to show sub-atomic particles. Note: Subscripts and superscripts are numbers written above, below, at the right, or at the left of the symbol of an element. What is the difference between a subscript and a superscript?

If a volume of material is composed of only one kind of atom (all oxygen atoms, for example) it is said to consist of a single element. In the case of some elements, the atoms do not become attached to other atoms of the same kind. These are called monatomic elements. What are some examples of monatomic elements? In the case of some other elements, the atoms are bonded together, usually in pairs. These are called diatomic elements. What are some diatomic elements? Are they solids, or liquids, or gases?

What is a compound? What is a molecule?

LABORATORY EXPERIENCE B.3.b.

Carbon Chains and Rings

Introduction:

If two like atoms are chemically combined, they form a diatomic molecule of the element. What if two or more unlike atoms are chemically combined? What is a compound? Do you know what carbon monoxide is? What about carbon dioxide? What does a molecule of carbon monoxide look like? A molecule of carbon dioxide? How do atoms combine to form molecules? Why must we make models in order to "see" molecules?

Materials and Equipment:

Small styrofoam balls (white, black, red)

Pipe cleaners (cut into one-inch lengths)

Collecting Data:

Review the structure of an atom of oxygen. (Laboratory Experience B.3.a.) How many electrons are there in the outer shell of an atom of an element? (Note: Hydrogen and helium are exceptions. Why?) How many electrons are there in the outer shell of oxygen? How many "holes" or "vacancies" are there in the outer shell of an oxygen atom? These "vacancies" make possible the combining ability of the atom. Chemists call the combining ability of an element its valence(s). What is the valence of oxygen? Take a small, white styrofoam ball and poke the proper number of holes into it to represent these valences. How many holes did you make? Should these holes be symmetrically arranged on the surface of the ball that represents the atom? Will they always retain the same spacial relationship to one another? Why or why not? Do not try to answer these questions definitely until later in the laboratory experience. You may then use one or more additional white balls if you need to do so.

Review the atomic structure of carbon. How many electrons are there in the outer shell. What is its valence? Use a black styrofoam ball to make a model of an atom of carbon. Poke the proper number of holes in it to represent its valence (the number of "vacancies" in its outer shell). How could you make a model of a molecule that contains one atom of carbon and one atom of oxygen? Make a model of such a molecule. Use one-inch lengths of pipe cleaner to insert in the holes in the balls to hold them together. This is a molecule of carbon monoxide. Are any valences of either atom still unused? How many? Which atom?

Another way to write carbon monoxide is

$$=C=O$$

This is called a structural formula. It shows two of the valences of carbon attached to an oxygen atom (O). The remaining two valences of carbon are unattached. This makes carbon monoxide (which also may be written with the simple formula CO) a dangerous gas. Why? In the blood, oxygen is carried by the red pigment hemoglobin. What happens when carbon monoxide is breathed into the lungs and comes in contact with the hemoglobin? What happens to an automobile driver when the muffler has a hole in it and carbon monoxide escapes into the car?

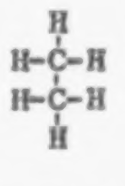
Now construct a model of a molecule of carbon dioxide. First, write the simple formula showing the number of each atom present in the compound. Then write the structural formula. Then construct the model. Are you able to use all the valences of all the atoms? How do the properties of carbon dioxide differ from those of carbon monoxide? Is carbon dioxide a dangerous gas? Why or why not?

Another gas that combines readily with carbon is hydrogen. What is the valence of hydrogen? Use red styrofoam balls for hydrogen atoms, poking holes in them to correspond to their valences. Make a molecule of a compound composed of carbon and hydrogen. Use as many hydrogen atoms as you need to satisfy all of the carbon valences. How many hydrogen atoms did you use? Write the structural formula for this compound. Now write the simple formula. This compound is a gas called methane. Can you see it? Can you smell it? Where does it occur naturally? Does it have any use?

Review the properties called "acid" and "basic" (alkaline). (See Laboratory Experience B.1.a.) A base has a combination of a hydrogen atom and an oxygen atom in a very close association, so that they are not ordinarily separated. Any such close association of two or more atoms is called a radical. It tends to hold together when chemical reactions (break-ups and recombinations) take place. The combination of a hydrogen and an oxygen is called a hydroxyl radical. It has a valence of one, and can be written -OH. Make a hydroxyl radical with your styrofoam balls by sticking a white ball and a red one together. Why would you expect this radical to have a valence of one? Make a hole in the side of one of the balls to indicate its valence. Which one?

The simple formula for methyl alcohol is CH_3OH. Starting with a model of a methane molecule (CH_4), use a hydroxyl radical to change it into a model of a methyl alcohol molecule. How will you do this? Write the structural formula for the methyl alcohol molecule. What is methyl alcohol? How is it used? Is it dangerous? Why?

Carbon atoms can form chains by attaching to one another, and partially satisfying one another's valences. Construct a model for this structural formula:



$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Write the simple formula for it. This substance is called ethane. What are its properties? Does it have any use? Substitute a hydroxyl radical for one of the hydrogens. Write the structural formula. This is ethyl alcohol. How is it used? Is it dangerous? Why or why not?

Every time another carbon atom is added to the chain, a new compound results. Try chains of three carbon atoms, four, five. First satisfy their valences with hydrogen atoms, then substitute a hydroxyl radical for one of the hydrogens on each. Find out the name of each of the carbon-hydrogen compounds, and the name for each compound after the hydroxyl radical is substituted. All of the compounds containing the hydroxyl radicals are called alcohols. Write simple formulas for each of the carbon-hydrogen compounds and each of the alcohols.

8. A German chemist named Kekule tried to devise a structural formula for benzene (C_6H_6). He is said to have been dozing in front of the fireplace after a long day in the laboratory, and to have dreamed of a ring of six carbon atoms instead of a chain. Can you construct a ring of six carbon atoms each of which has only one valence left for attachment of a hydrogen atom? How will you attach the other three valences of each carbon atom? What kind of substance is benzene? What are its properties?

Substitute a hydroxyl radical for one of the hydrogen atoms. This is benzyl alcohol. Draw the structural formula. Write the simple formula.

Hypothesis:

It is possible to construct physical models which enables us to visualize atoms and molecules (things which we cannot see) if we know their composition, and know their valences or combining properties.

Is this a valid hypothesis? Have we tested it? Is it generally applicable?

Follow-Up:

Find out if the atoms of any other chemical element are able to combine with atoms like themselves to form chains and rings. Do any of these atoms combine with carbon? What about nitrogen? What are the principal chemical elements that are found in living matter? How is it possible to define life as we know it on earth in terms of the versatile combining properties of certain chemical elements? Might other forms of life be possible on planets with very different physical environments (e.g. hotter or colder), based on other chemical elements with very versatile combining properties?

LABORATORY EXPERIENCE B.3.c.

A Very Complex Molecule: DNA, the Substance That Carries Heredity

Introduction:

For a long time scientists have known that hereditary characteristics: brown and blue eyes, curly and straight hair, white and red flowers, tall and short peas, black and white guinea pigs, are passed on from parents to offspring through rod-like structures in the nuclei of the cells called chromosomes. They are present in the chromosomes in the form of units called genes.

Chromosomes can be seen readily under the microscope, if the cells are properly prepared, and stained with certain dyes, but genes are too small to be seen, and can be studied only on the basis of what they do. Indeed, until recently, it was not certain whether individual genes were like "beads on a string", or were simply a set of relationships within a specific area of the chromosome. Nevertheless, by studying the action of genes and their behavior in relation to one another along the length of particular chromosomes, scientists were able to build up accurate maps showing where specific genes were located.

Now scientists have found that the actual hereditary material (the material which makes up the substance of the genes) is a complex molecule called deoxyribonucleic acid (DNA). The DNA constitutes the central portions ("cores") of the rod-like chromosomes. The DNA core of a chromosome is surrounded by a sheath of protein material.

We now have a very good understanding of what the structure of a DNA molecule is like. It consists of varied combinations of a limited number of different kinds of units or sub-units. These units are themselves molecules, which combine in DNA to make a kind of super-molecule (macromolecule). They are: (1) a sugar, called deoxyribose, (2) a phosphate, and (3) four kinds of protein bases; two smaller ones, thymine and cytosine, and two larger ones, adenine and guanine.

For our purposes, we will abbreviate the sugar as "S", the phosphate as "P", and the four bases as "T", "C", "A", and "G". The two smaller bases match one another in size, and the two larger ones also match one another. The A and the T, a large and a small one, will attach to one another, and the C and the G, a large one and a small one, will do the same. When the bases do this, they form two kinds of rod-like structures of equal length: AT and CG. This matching of bases is important in the structure of the DNA molecule. They will not normally attach to one another in any other way.

The S and P sub-molecules became linked with one another end-to-end -S-P-S-P-S-P-S-P- to form a chain. The AT and CG "rods" become attached to the S's of the chain.

The DNA molecule consists of a kind of "spiral ladder." The sides of the ladder are SP chains. The cross-pieces or rungs(steps) of the ladder are pairs of protein bases, the AT and CG rods. These link together the S's of the two sides. They may be attached to the sides as AT and CG, or they may be reversed: TA and GC. The reversals are important since they make possible four structural variables instead of only two.

The DNA ladder forms a spiral because the sizes and arrangement of the sub-molecules are such that when they are put together there is a natural "twist" to the structure. A single spiral is called a helix. A twisted ladder is called a double helix. A gene is believed to consist of a series of from 20 to 2,000 sequential rings of the ladder. The DNA molecules are so long in proportion to the number of "rungs" that they contain that an immense number of such genes can be located in them. The total number of rings in all human chromosomes is believed to be about six billion.

Because of the great number of different structural arrangements that the four variables make possible, the series of genes in all of the chromosomes is able to present a set of "coded directions", telling how the living organism is to develop. Therefore it is possible to say that the DNA furnishes a kind of "blueprint" for the construction and behavior of the living organism.

Hypothesis:

While obviously it is not possible to construct a scale model of a DNA macromolecule, it is possible to make a model that will show some of the relationships within a small section of such a molecule. Additional information obtained through reading can then be fitted into a more meaningful mental picture.

Equipment and Materials:

Small size rubber tubing

Round toothpicks with sharply pointed ends

Six different colors of paint, preferably blue, red, yellow, green, brown, and black

Small paint brushes

Two wooden dowels, with sharply pointed ends, the same length as the toothpicks

A pointed instrument, such as an ice pick

Ruler

Two small hooks with screws, for attachment to the two dowels

String

Building the Model:

1. Use two pieces of small size rubber tubing of equal length. Any length from 18 inches to three feet will be satisfactory.

2. Measure and mark alternating segments of one-fourth inch and one-half inch along the entire length of each piece of tubing.

3. Paint the quarter-inch segments black, and the half-inch segments brown. Note: the smaller black segments will now represent the phosphates (P), and the larger brown segments will represent the sugars(S) along the S-P chain.

4. Use a sufficient number of round toothpicks with pointed ends to equal the number of brown segments (S) along your S-P chain.

5. Measure two segments on each toothpick: one segment to constitute one-third of its length, and the other segment two-thirds of its length.

6. Divide the toothpicks into two groups of equal size.

7. In Group I, paint the short segment of the toothpicks yellow and the long segments green.
Note: the yellow segments of this group will now represent thymine(T), and the green segments adenine(A). The two together represent an AT "rod".

8. In Group II, paint the short segments of the toothpicks red, and the long segments blue.
Note: the red segments of this group will now represent cytosine(C), and the green segments guanine(G). The two together represent a CG "rod".

9. Using an ice pick or similar pointed instrument, punch a small hole (the size of the pointed ends of the round toothpicks) at the midpoint of each of the brown segments (S's) along each piece of rubber tubing. Be sure to punch the holes in a straight line on one side of the tubing. Avoid making the holes any larger than necessary.

10. Mix the two groups of toothpicks thoroughly.

11. Insert a toothpick in each pair of holes, linking the two tubes. Insert the toothpicks in as many different arrangements and orders as possible: either yellow-green or green-yellow; either red-blue or blue-red; with a yellow and green above or below a red and blue, or with two or more of the same kind succeeding one another.

12. Now insert a small hook with a screw at the midpoint of each of two small wooden dowels pointed at each end.

13. With the ice pick, punch a hole in each end of each of the rubber tubes, on the same side of and in line with the toothpick holes, but located between the last toothpick hole and the end. Insert a wooden dowel connecting the ends of the two tubes at each end of your "ladder." The dowels will serve to stabilize the ladder, and the hooks in the dowels will furnish a means for attaching and holding it.

14. Attach a piece of string to each hook. Attach the string holding one end of the ladder to a fixed point.

15. Hold the dowel at the other end in your hand, and rotate it to the left. In doing so be careful not to put too great a strain on the ladder. You may attach the end you are holding to another fixed point if you wish.

16. You now have a model showing some of the features of a DNA molecule.

Read the description of the DNA molecule in *The Cell* (Life Science Library), Chapter 3, "The Architect and Master Builder" pages 68-74, by John Pfeiffer and the editors of *Life*, published by Time, Incorporated, New York, 1964.

Have you verified the hypothesis stated earlier? What characteristics of DNA *have* you illustrated? What characteristics are there that you *have not* illustrated? Can you think of any way that you might illustrate some of these? What ones are there that you could not illustrate at all? What about size relations? What about overall complexity?

It is a unique characteristic of DNA that it is able to *replicate* itself; that is, to make more of itself. This is the basis for *cell division* and *reproduction*. How does the DNA molecule do this? Can you *understand* this in terms of your model? Can you think of anyway that you could change your model so that you could *show* it?

Follow-Up:

What is a *mutation*? Explain what a mutation is in terms of your model. What is the importance of mutations? What kinds of things may cause them to occur? Are they always harmful or may they sometimes by helpful?

LABORATORY EXPERIENCE B.3.d.

Models of Crystals*

Introduction:

Many minerals appear in the form of crystals. Examine crystals of halite (common table salt) and other minerals that your teacher will furnish you. Do they have definite geometric shapes? Were they cut to those shapes or did they form naturally? Notice the smooth flat surfaces called crystal faces.

How many faces do the halite crystals have? Measure the angle between two faces. Try this on several angles on different halite cubes. What do you discover? Examine the geometric shape, the crystal faces, and the angle between the faces of several calcite crystals. Examine quartz crystals, pyrite crystals, sulfur crystals.

What causes minerals to form these regular geometric shapes with smooth crystal faces and fixed angles? Is there some special arrangement of atoms or molecules that makes a crystal? Could you "picture" (make a mental model) of an arrangement of atoms or molecules that would make a crystal? If you knew how many atoms? What else would you need to know? Could you make a 3-dimensional physical model? Would this be better? Why?

Equipment and Materials:

Crystals of halite, calcite, quartz, pyrite, sulphur, olivine, hornblende, biotite mica, orthoclase, feldspar

Styrofoam balls of two sizes and several different colors

Pipe cleaners

Calipers

Protractor

Collecting Data:

Examine the halite crystals again. It is composed of equal numbers of sodium ions and chlorine ions. What is the difference between an ion and an atom? Why are these ions? Let large styrofoam balls of one color represent chlorine ions, and small styrofoam balls of another color represent sodium ions. Use pieces of pipe cleaner to hold them together. Construct a crystal of halite. Remember that it must form a cube. Be sure that every chlorine ion touches a sodium ion. Be sure also to use the same number of chlorine ions and sodium ions. You have built a physical model of a halite crystal. Examine a halite crystal with a magnifier.

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*Revised in collaboration with Mr. J. F. Disinger, Irondequoit Central School District, Rochester, New York.

For living things oxygen is the most important element in the air. Let large styrofoam balls of one color represent oxygen atoms. Two oxygen atoms join to form one oxygen molecule. This is the form in which oxygen exists in the air. Using a piece of pipe cleaner, make a model of an oxygen molecule.

Let smaller balls of a different color represent atoms of hydrogen. Two ions of hydrogen (+) combine with one ion of oxygen (-) to form a molecule of water. Connect two small balls (representing hydrogen ions) to one large ball (representing an oxygen ion) in such a way that the centers of the small balls are approximately 105 degrees apart. This is a model of a water molecule. Make about 20 water molecule models. Be careful to fasten the two hydrogen ion models to the oxygen ion model both tightly and at the proper angle. Do not fasten the models of molecules to one another, but jumble the models so that they fit as tightly as possible. This is a model of liquid water. See how small a volume you can create.

Now fasten the molecule models together; be sure that positively charged hydrogen ions are in contact only with negatively charged oxygen ions; also be sure to make your model three-dimensional. Compare the volume occupied by this model of solid water (ice) to that occupied by an equal mass of liquid water. Which is denser, water or ice? How does your model help explain why ice floats on top of lakes?

The most common minerals of the earth's crust contain oxygen and silicon. Using a small ball (of a different color) to represent silicon, combine four large balls (oxygen) and one small ball (silicon). Arrange them as compactly as possible. All of the oxygen balls should be at an equal distance from the silicon ball. This is a model of a silicon-oxygen tetrahedron---the basic pattern of the silicate minerals of the earth's crust. What is the formula for this tetrahedron? Build a second tetrahedron. Now join the two tetrahedrons so they share an oxygen atom from one of them. In this way the two tetrahedrons have only seven oxygen atoms. See if you can build a chain of tetrahedrons by joining them together in this way.

Quartz consists of only silicon and oxygen. Each silicon-oxygen tetrahedron shares all four oxygen atoms with neighboring tetrahedrons. Build a model of a quartz crystal and examine it. Examine quartz sand with a magnifier.

Follow-Up:

Calcite is a mineral consisting of calcium carbonate ($CaCO_3$), crystallized in hexagonal (six-sided) form. Common examples of it are limestone and marble. A calcite crystal is more complicated in its internal structure than a halite crystal, but it may also be considered, in a simplified fashion, to consist of equal numbers of positive and negative ions (Ca^+ and CO_3^-). Construct a model of a calcite crystal by using two different sizes and colors of styrofoam balls. Check the angles of the faces to form a correctly-shaped crystal. Examine a calcite crystal with a magnifier

The mineral olivine is an iron-magnesium silicate. The silicon-oxygen tetrahedrons are held together by iron and magnesium atoms. These lie between the tetrahedrons in no fixed order or arrangement or number. Using different colored spheres to represent the iron and the magnesium, build a model of olivine. Examine a crystal of olivine.

The mineral hornblende is also an iron-magnesium silicate. The silicon-oxygen tetrahedrons form chains by sharing first two and then three oxygen atoms. The iron and magnesium atoms lie between them again in no fixed number or arrangement. Build a model of hornblende, and examine a crystal of hornblende.

Biotite mica is a silicate mineral in which the silicon-oxygen tetrahedrons share three oxygen atoms to make sheets. Iron, magnesium and other mineral atoms fit between. Build a model and examine a specimen of the mineral.

The feldspars are the most common silicate minerals. All of the oxygen atoms of the tetrahedrons are shared by neighboring tetrahedrons, but aluminum atoms take the place of some of the silicon atoms, and potassium, sodium and calcium atoms also may be present. This is a very complex model, but try to make one, using different colored spheres to represent the different atoms.

Diamond and graphite both consist of nothing but carbon atoms. Construct a model to show how the atoms could be arranged so that diamond is the hardest known natural substance and graphite is so soft and flaky that it can be used as a lubricant. What factors seem to determine which form the mineral will take?

How does the internal structure of the atoms affect the physical properties of the mineral? What factors other than internal structure of the atoms would affect the physical properties of a mineral?

LABORATORY EXPERIENCE B.3.e.

Mathematics as Models

Introduction:

You are familiar with equations of different kinds, but did you ever think of 2+3=5 as a model? Probably not, but think about it now. What is "2"? What is "3"? Really, they are models of two "somethings" and three "somethings" that are real. What about the signs + and =? What are they models for? Are all equations models? What about formulas?

Materials and Equipment:

Squares of paper 1" x 1"

Ruler

24 identical cubes of wood or 24 identical children's blocks

Various circular objects: coin, drinking glass, saucer, plate, et cetera.

Pieces of string

Collecting Data:

Arrange the squares of paper on your desk until it is entirely covered. How many squares did you use? How many rows of squares did you use? How many squares are in each row? You now have three numbers. Make an equation using these three numbers. Your equation is a model of the paper squares on your desk. What is the formula for this equation? Is this formula a model? Why or why not?

Take the 24 wooden blocks. Use all of them to make a rectangular prism. Write the equation (model) for that shape. Remember the structure has height, length, and width. Rearrange the blocks and write another equation. Continue to make shapes with the blocks and write the equations until you have exhausted all possibilities. What is the formula for these equations?

A familiar mathematical model is the formula $C=\pi d$. What is π?

Work with pieces of string and several different size circles - a coin, a glass, a saucer, a plate - to verify this mathematical model.

One of Newton's Laws of Motion is involved in the following data:

DATA I

Mass	Force	Acceleration
20 gm.	30 gm.	6 cm per sec. per sec.
20 gm.	40 gm.	8 " " " " "
20 gm.	50 gm.	10 " " " " "

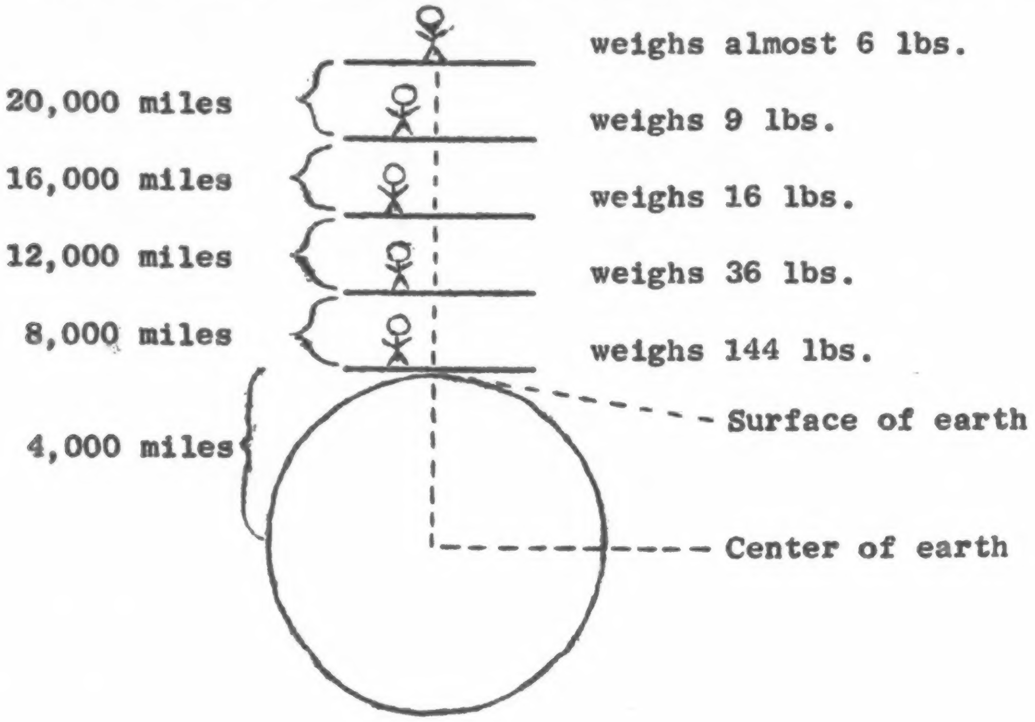
Mass	Force	Acceleration
20 gm.	60 gm.	12 cm per sec. per sec.
20 gm.	70 gm.	14 " " " " "

DATA II

Mass	Force	Acceleration
20 gm.	30 gm.	6 cm per sec. per sec.
30 gm.	30 gm.	4 " " " " "
40 gm.	30 gm.	3 " " " " "
60 gm.	30 gm.	2 " " " " "
120 gm.	30 gm.	1 " " " " "

What difference do you notice in the two sets of data? What are such relationships called? Write the mathematical model for each.

You have heard a great deal about "weightlessness" of astronauts in orbit. Below is a diagram which illustrates the effect of distance upon the weight of a man. Try to develop a mathematical model for this relationship.


weighs almost 6 lbs.
20,000 miles
weighs 9 lbs.
16,000 miles
weighs 16 lbs.
12,000 miles
weighs 36 lbs.
8,000 miles
weighs 144 lbs.
Surface of earth
4,000 miles
Center of earth

Follow-Up:

Additional materials and supplies:

- Opaque cardboard with one-inch hole
- Cardboard marked with one-inch squares
- Source of light
- Ruler

Place the first cardboard upright in a holder one foot from the light. Do not move this cardboard. Place the second cardboard as close to the first as possible and still be able to see how many squares are illuminated. Record the data. Move the second cardboard 2 feet from the candle. Record how many squares are illuminated at this point. Repeat at 3 feet. What is the mathematical relationship between the distance from the source of light and the area illuminated? What happens to the intensity of the light on each square as the distance is increased? What is the mathematical relationship between the distance and the light intensity? Write the mathematical model for both relationships.

LABORATORY EXPERIENCE B.3.f.

Models for Probability: Heredity

Introduction:

Have you ever wondered why some people have blue eyes and some have brown eyes? Or why some people have curly hair and some straight? Or why some people are tall and others short? Or why some people have skin of one color and some another? Characteristics of people depend on the heredity factors that they carry. When these heredity factors are combined in the offspring of two parents they behave in the same way that coins do when they are tossed.

Heredity factors are called genes. They exist in pairs. When the germ cells that contain the genes get ready for fertilization, the members of each gene pair separate. Each member of the pair goes into a different germ cell.

Ther germ cells from the two parents (sperms from the male and ova or eggs from the female) are united at the time of fertilization to form a new individual. Each parent contributes one member of each pair of genes. The new individual therefore starts out in life with one member of each pair of genes from the father and one from the mother.

Although some characteristics, like height and skin color, are determined by several pairs of genes working together, many characteristics are determined by a single pair of genes. An example of a characteristic determined by a single pair of genes in curly hair.* A curly-haired individual carries two genes for curly. We will use "AA" as a model for curly hair. A straight-haired individual has two genes for straight. We will use "aa" as a model for straight hair. An individual with one gene for curly and one gene for straight (model "Aa") has wavy hair.

If a curly haired person marries another who is also curly-haired, we can use this as a model to represent their marriage:

AA X AA

When the members of the gene pair separate before fertilization and go into separate germ cells, the model looks like this:

$$\begin{tikzcd} & \text{AA (one parent)} \arrow[dl] \arrow[dr] & & & \text{AA (other parent)} \arrow[dl] \arrow[dr] & \\ \text{(germ cells) (A)} & & \text{(A)} & \text{(A)} & & \text{(A) (germ cells)} \end{tikzcd}$$

Note that all germ cells of both parents contain a single gene: (A). When the germ cells unite at fertilization this is the model:

$$\begin{tikzcd} \text{(A)} \arrow[dr] & & \text{(A)} \arrow[dl] \\ & \text{AA (new individual)} & \end{tikzcd}$$

2

All of the new individuals contain two genes for curly, and all of them are curly-haired.

---

*This is true for Caucasoid (so-called "white") people. Mongoloid people (Chinese, American Indians and others) have only straight hair. Negroid (brown and black) people have a gene for curly which is so strong that it prevents the expression of all other hair genes.

The same kind of thing happens when two straight-haired individuals marry:

aa X aa (parents)
(a) (a) (a) (a) (germ cells)

When the germ cells unite at fertilization, all of the new individuals contain two genes for straight, and all of them are straight-haired.

(a) (a) (germ cells)
aa (new individual)

When a curly haired individual marries a straight-haired individual:

AA X aa

All of the germ cells from the curly-haired parent carry only curly genes, and all of the germ cells from the straight-haired parent carry only straight genes:

AA aa (parents)
(A) (A) (a) (a) (germ cells)

At fertilization curly genes have to unite with straight genes:

A a (one germ cell from each parent)
Aa

and the new individuals that are formed are all Aa, and are therefore wavy-haired.

What happens if a wavy-haired person marries another wavy-haired person?

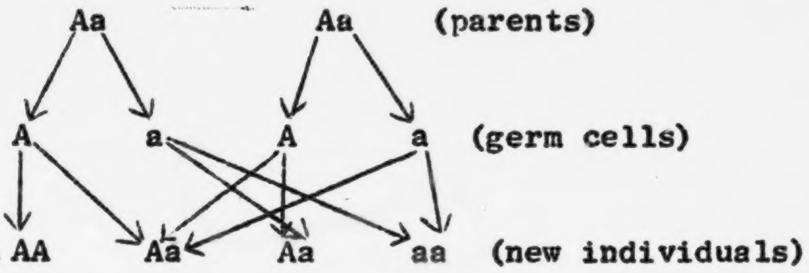
Aa X Aa

When the gene pairs separate:

Aa Aa (parents)
A a A a (germ cells)

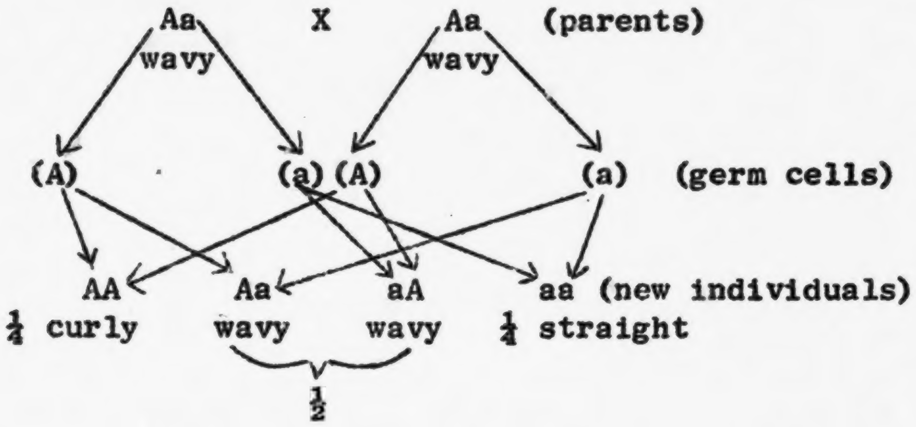
Half of the germ cell from ach parent carry curly half carry straight.

When fertilization takes place there is an equal chance of a curly gene from one parent combining with either a curly or straight gene from the other parent. And there is the same chance of a straight gene from one parent combining with either a curly or straight gene from the other parent:


Aa
Aa
(parents)
A
a
A
a
(germ cells)
AA
Aa
Aa
aa
(new individuals)

Thus there is one chance in four of a new individual that is curly-haired, two chances in four of new individuals that are wavy-haired, and one chance in four of a new individual that is straight-haired. With a large number of new individuals you could expect a ratio of ¼ curly, ½ wavy, and ¼ straight.

Let us now look again at what happens when a wavy-haired person marries another person with wavy hair, and pull it together into a single picture:


Aa
wavy
X
Aa
wavy
(parents)
(A)
(a)
(A)
(a)
(germ cells)
AA
Aa
aA
aa
(new individuals)
¼ curly
wavy
wavy
¼ straight
½

This picture is a mathematical model. Another way to show it is with this model:

(germ cells of the other parent)

	A	a
A	A A	A a
a	a A	a a

(germ cells of one parent)

(new individuals)

The four kinds of recombinations that take place in the new individuals occur in equal numbers:

¼AA ¼Aa ¼aA ¼aa

Two of them, however, (Aa and aA) are really the same. Therefore, the result is a ratio of 1:2:1.

Materials and Equipment:

Pennies

Pencil and paper

Collecting Data:

Coins, when they are tossed, behave according to chance, and when many tosses are considered together, they follow the law of probability. Genes when they separate and recombine also behave according to chance, and follow the law of probability when many recombinations are considered together. It is possible, therefore, to set up a physical model of a heredity cross involving a single pair of genes by tossing two pennies.

When two pennies are tossed together, they are equally likely to fall:

"heads-heads"
"heads-tails"
"tails-heads"
"tails-tails"

There is one chance in four of their falling "heads-heads," two chances in four of their falling either "heads-tails" or "tails-heads," and one chance in four of their falling "tails-tails". If we name the heads "(A)" and "(A)", and the tails "(a)" and "(a)" then:

AA stands for "heads-heads"
Aa and aA stand for "head-tails" or "tails-heads," and
aa stands for "tails-tails"

If the two pennies are tossed together many times an approximate ratio of 1:2:1 will result.

Toss two pennies together 100 times and see how closely you can approximate a 1:2:1 ratio. If it does not come out exactly 1:2:1, what kind of warping factors do you think might have interfered with obtaining a perfect ratio? Do you think that 1000 tosses would have resulted in a more nearly perfect ratio than 100 tosses? Why?

You have constructed models (a mathematical model and a physical model) of a marriage between two wavy-haired individuals. If such a marriage produced four children, do you think that one would be curly-haired, two wavy-haired, and one straight-haired? Why, or why not?

Follow-Up:

In many cases of inheritance based on a single gene pair, one member of the pair is dominant over the other. In such a case, the other member of the pair is said to be recessive. If both members of such a pair, such as (B) and (b), are present together: Bb, only the (B) is shown. The (b) is present but is covered up by the dominant. In such cases you cannot tell the difference between a Bb individual and a BB individual. There is some evidence that right-handedness and left-handedness in humans inherited in this way, with right-handedness dominant to left-handedness. Set up a mathematical model of a case in which a right-handed individual who carries left-handedness as a recessive is married to another right-handed individual who also carries left-handedness in the same way. What will be the chances of their children being right-handed or left-handed?

Some human characteristics, such as height, skin color, and general mental ability, depend on several pairs of genes, working together. None of these genes show dominance or recessiveness. This type of inheritance is called multiple factor inheritance. Using height as an example, different individuals possess varying numbers of height genes. If they possess many height genes, they are tall (or they can be tall if their environment has been favorable enough during their growth period to allow them to grow to be as tall as their heredity will make possible). If they possess few height genes, they are short, regardless of how favorable their environment may be.

When two tall people marry, their children generally tend to be tall like their parents. When two short people marry, their children generally tend to be short. People of intermediate height (neither tall nor short) possess fewer height genes than tall people, but more of them than short people. Their children may be taller than they are, shorter than they are, or intermediate in height like the parents.

We don't know how many pairs of genes work together to determine height in people. If, however, we assume that there are six pairs, we can construct a physical model showing how these genes are inherited in a mixed population consisting of people of varying heights, who intermarry freely with one another. (By this we mean that a tall person is as likely to marry a short or intermediate person as another tall person, and that all other possible combinations are equally likely to occur.)

Let six pennies represent the six pairs of genes. Toss them together. Let the tails on the pennies represent height genes. Toss them 100 times. Construct a graph or frequency curve, recording the number of tails that turn up in each of the 100 cases. It will look somewhat like this:

			X				
		X	X	X			
	X	X	X	X	X		
X	X	X	X	X	X	X	
0T	1T	2T	3T	4T	5T	6T	(number of tails)

Which are the tallest individuals shown on the graph? Which are the shortest? Those of intermediate height? Do you get something approximating a normal curve? Why? How do the relative numbers of the different height classes on your frequency distribution compare to the relative numbers of people of different heights that you see in the general population around you? In your class?

Find out whether the tall students in your class have tall parents, the short students short parents, and the intermediate height students intermediate height parents. Do you find a relationship between height of children and height of parents? Do you find exceptions to such a relationship? Few exceptions? Many exceptions? What is the effect of environment on growth in height? How important is it? How does it operate in relation to heredity?

Can it reduce the height to which heredity would allow a person to grow? Can it increase the height beyond that to which heredity would allow a person to grow? Why, or why not?

People during the Middle Ages were much smaller than modern people? We know this from looking at the suits of armor the knights wore. Why were they small? The men in the U.S. Army during World War I were smaller on the average than the soldiers during World War II. Why were they smaller?

Some human characteristics which depend on many pairs of genes are more affected by environment than others. General mental ability is believed to be inherited in this way, and is greatly affected by environment, especially during childhood, just as height is. Skin color, on the other hand, is little affected by environment. Why?

LABORATORY EXPERIENCE B.3.g.

Making a Model of the Solar System

Introduction:

Your physical models of atoms, molecules, and crystals have helped you to visualize things that are too small to see. Is it possible also to use a model in order to visualize something that is too large to see? Could you construct a model of the solar system? What materials could you use? Could you show the comparative sizes of the sun and planets? Could you show the relative distance from each planet to the sun? What about natural satellites (moons)? What about artificial satellites? Could you show meteors? Comets?

Hypothesis:

Information concerning the solar system and its size, and the relationships within it, can be better understood if it is thought of in terms of a model constructed on the basis of relative sizes and/or relative distances.

Equipment and Materials:

Styrofoam balls

Tinkertoy hubs and sticks

Wire

Reference books on the solar system and universe

Collecting Data:

Get a list of the planets and their sizes and distances from the sun. If you were to let a one-inch styrofoam ball represent earth, determine how large, in proportion, each planet should be. What is the diameter of the sun? How large should it be in proportion? Can you devise a better scale? What could you use as a model for the sun, making everything else proportional to it? If you were to use the largest styrofoam ball that you can obtain as a model for the sun, how large would the earth be? The moon? What other kinds of large balls could you use as a model for the sun?

Get the distance from the sun to each planet. Let one inch represent the distance from the sun to Mercury. On the same scale, how far from the sun would each planet have to be? In doing this, we are using a different scale for distance than we used for size. Why are we doing this? Is it possible by using two different scales (one for size and one for distance) to construct a valid physical model of the solar system? A meaningful or usable physical model? Why, or why not?

If your model for the sun were a basketball in the center of your classroom, and you used the same scale for proportional sizes and distances throughout, where and how large would the earth be? The moon? Jupiter? Pluto?--Determine the diameter of the basketball in centimeters, and then use larger and smaller units of the metric system to calculate other sizes and distances. Do not hesitate to use fractions of millimeters. How can you go about determining the diameter of the basketball in centimeters?

See if you can find the distance from the sun to the nearest star, and determine how this distance would be represented in your model. Finally, state your distances in terms of familiar approximations; for example, "the length of the classroom," "the length of the school ground," "a city block", "ten city blocks", "the distance to the next city", "the distance to San Francisco", "the distance to Australia", "the distance to the moon."

Using the same scale for sizes and distances, is it possible to construct a valid and meaningful or usable mental model of the solar system and its relationship to the rest of the universe?

Is the hypothesis, as stated earlier, supported or not?

Follow-Up:

Using styrofoam balls, tinkertoy hubs and sticks, and wire, try to put together a model of the solar system. In doing this, do not attempt to show relative sizes and distances. Can you devise a way to show rotation? Revolution? Satellites around planets? The rings around Saturn?

B.4. Idea of Developing Terminology

Idea Bridge: The Need to Name Things

To the mind of primitive man, everything in his world was filled with conscious life. This was true not only of other humans. All other animals, plants, mountains, rivers, waterfalls, the sky, the sun, moon, and stars, and all of the forces of nature were alive and had minds and wills of their own. He believed that these conscious spirits were not only alive but were potentially dangerous to him, and must be kept in a good humour if he were to survive in the midst of them. He believed that this might be done through obedience to various taboos ("thou shalt nots"), and through sacrifices, prayers, and incantations. The best single way to control a dangerous spirit, however, was to know its name and be able to use it. This name was generally a secret, known only to the initiated, that is, to those who were "in on the secret."

Modern science has its roots in magic. Up through medieval times the scientist and the magician were close to one another; in many cases they were one and the same. Even now, to many people the scientist is somewhat akin to a magician. One reason for studying science is to show that this is not so.

The beginning stage of any developing science is always descriptive. Early scientists described the things and processes that they found in nature, and gave them names. Primitive man gave a name to the spirit that he believed was in the waterfall or in the storm, and thus believed that he had achieved a kind of control over it when he was able to call it by its name. The scientist gave a name in the same way to a phenomenon or a process (electricity, photosynthesis, respiration, inertia, enzyme, hormone, gene) and felt that he could now "see around it" and go on to a new problem in which the thing that he had named played a contributing part. Only later did other scientists go beyond the descriptive level to the analytical level,and thus begin to answer questions of "how" and "why" in regard to what they had found. In the meantime, scientists, like their long-lost brothers, the primitive magicians, continued to give names to other new things and processes. Thus scientific terminology grew and became a part of the language.

Natural laws, which are descriptions of consistently operating natural processes and patterns, could not be stated or expressed without the use of scientific terminology. After all, you have to call these things something, and since many of them were not known when the language was being developed, there are no natural or common names for them. Terms like ohms, volts, genes, atoms, and molecules did not need to be used or talked about or written about until scientists began to study the phenomena to which they belong. Scientists, therefore, have always been involved in the creation of new words.

LABORATORY EXPERIENCE B.4.a.

Changes in Language

Introduction:

People in our time, that is, in the last third of the twentieth century, have a larger working vocabulary than people had one hundred years ago in the last third of the ninteenth century. Modern people have more things to talk about and write about. People in the ninteenth century, however, had a larger working vocabulary than their counterparts in the eighteenth century for the same reason. Language grows to meet the needs of the people who use it.

Modern man not only has a larger working vocabulary than his predecessors, but also quite a different one. There are new names for new things. The names for the older things which our new things have replaced become obsolete and will ultimately be forgotten. If these words are preserved at all, they will be found only in old, written records; no longer in the vocabulary of everyday speech and writing.

Thus language undergoes evolutionary change, paralleling the changes that take place in the things that man uses, and the situations under which he lives and works.

Materials and Equipment:

Paper and pencil

A keen ear for listening

A good memory for words

A lively imagination

Access to parents or other older persons

Collecting Data:

What is slang? Can you think of any slang words that are used by young people, but rarely by adults? Do you use slang words that your parents do not use? Write down as many slang words that are used by your own generation of young people as you can think of. Talk to your parents or other people your parents' age, and find out some of the slang words that they used when they were young that your generation does not use. Did some of their words have the same meaning as the different words that your generation uses? Do your parents ever still use the slang words of their youth?

You can have fun doing this, and help "educate" your parents in doing so. Do your parents need educating in some ways? What is meant by the "gap" between generations? Do you suppose that there was the same kind of gap between your parents and their parents?

Do some slang words endure (or survive) and become a permanent part of the language, or do they always give way to new slang? In talking with your parents, see if you can find an answer to this question?

Make a list of new words and phrases that have come into the language as a result of radio, television, space travel, the nuclear bomb, the automobile, the airplane, and any other major inventions that have become a part of modern life.

Can you think of any words that have ceased to play any significant part in everyday language as a result of the abandonment of the use of the things with which they are associated? What about words associated with the use of horses for transportation and agriculture? What about fireplaces and stoves for heating? What about articles of women's and men's clothing? Any others?

Can you think of any words that are "on their way out"---that is, their meaning is still understood, but they are no longer in common use, either in speaking or writing?

Find words that were used in the late 1500's and early 1600's, the time of Queen Elizabeth I, William Shakespeare and the King James translation of the Christian Bible. How did the language then differ from now? What is "Middle English"? Are there any places where some of the elements of this antique form of English are still spoken? How did this form of the English language differ from the English that was used in still earlier times? Why?

Are there any songs that are still sung which are survivals of the time when Middle English was spoken? Where have they been found? Have your ever heard any of them? Who sings them now? Are any of them on records? Try to listen to some of them.

Hypothesis:

Can you suggest a hypothesis to describe how and why a language evolves (changes) in terms of the vocabulary that it uses? In the light of your hypothesis, what changes do you think may have taken place in the English language in another 300 years? What will determine that nature and the extent of the changes that occur? Would a present-day person be able to understand the English of 2200 A.D.?

Follow-Up:

Why do old words and old language forms survive longest in remote, poor soil, hilly or mountainous regions? Why do they also survive in the rituals of conservative churches (for example, an old form of Greek in the Greek Orthodox Church, Old Slavonic in the Russian Orthodox Church, Coptic in the Ethiopian Church, Hebrew in the Jewish services, Middle English in some Protestant Churches, and, until recently, Latin in the Roman Catholic Church). What relationship is there between the survival of old language forms in these two seemingly unrelated situations?

What is a "living fossil?" What is meant by the "survival of archaic forms in relict areas?" Look up "archaic" and "relict," and then try to answer this question, What examples of this are there, other than in the realm of language? How are all of these related? Why?

LABORATORY EXPERIENCE B.4.b.

Scientific Terminology

Introduction:

"Twas brillig and the slithy toves
Did gyre and gimble in the wabe
All mimsy were the borogoves
And the mome wraithes outgrabe"*

What was the occasion for the above quotation? What do you think the author meant to say? What picture(s) does this rhyme call forth in your mind? What do you "see"? Try to describe what you "see".

Have you ever invented a word? You will probably say that you never have.---And yet this may not be true, even though you think it is. Does your family still use some childhood words of yours? Possibly these were mispronunciations of ordinary words, or even wholly new words that you used as a small child, just learning to talk. Families start to use these words because they think the childhood talk is "cute", or "clever", or "quaint", and then later on they cherish the words for memory's sake.

A little boy once called apple pie "woofle pie," possibly through misunderstanding what his elders called it. His parents, thinking it "cute" or "clever", picked up the word and continued to use it. Later, when he was grown, this boy went to the university and lived in a house with six other students. They all learned to call apples "woofles." Still later, when these students had homes of their own, their children learned the word. Thus it passed into another generation. How long may this continue?

Would it be possible just to make a new word, and have it come to mean something? Many years ago, in a New England college town, one student made a wager with another student that he could not do this. The second student accepted the challenge. That night when the whole town was asleep, he took chalk and wrote QUIZ on sidewalks and walls all over town. The next morning everyone who saw this wondered what it meant. Since it was a combination of letters that could easily be pronounced and remembered, it came to mean an "unknown", a "question," and then finally, a set of questions, or an examination, expecially an informal or unannounced one.

Scientists, in attempting to describe the natural world and its behavior as they have discovered it to be, have developed or invented words (terminology) as they have needed to do so. They have done this in two ways:

(1) They have given limited or precise meaning to common, everyday words, in order to use them to refer to a particular thing, or phenomenon, or situation, or behavior. In this case we may say that scientists have made terminology by "word sharpening."

(2) They have created wholly new words to fit their needs and uses.

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*From Through the Looking Glass, by Lewis Carroll

We may call this process the making of "gobbledygook."* These are words or terms that are understood only by people in a particular scientific field or discipline.

Materials and Equipment:

Paper and pencil

A dictionary

25 miscellaneous objects of manageable size, and of as great variety as possible

A lively imagination

Collecting Data:

You will have a better understanding of the nature of scientific terminology if you try to arrive at a decision as to whether particular specific terms are the result of "word sharpening", or constitute "gobbledygook," manufactured to meet a particular need for scientific description. Look up the meanings of the following scientific terms, and try to make this decision in the case of each of them. (Note: A good basis for deciding might be to see if a word has any meaning or definition other than its scientific one. If you cannot find the word in a standard dictionary, what do you think this might indicate?)

Community (as used in ecology)

Succession (as used in ecology)

Climax (as used in ecology)

Gene (as used in genetics)

Chromosome (as used in genetics)

Dominant (as used in genetics)

Recessive (as used in genetics)

Enzyme (as used in biology or chemistry)

Deoxyribonucleic acid (as used in biology or chemistry)

Ribosome (as used in biology)

Catalyst (as used in chemistry)

Ion (as used in chemistry)

---

*"Gobbledygook" is a word which was invented by writers in Time magazine to refer to phraseology that is understood only by a small group, or "inner circle," or the initiated. The word gobbledygook itself is an example of the making of "gobbledygook."

Hydroxyl (as used in chemistry)

Base (as used in chemistry)

Inertia (as used in physics)

Brachycephalic (as used in anthropology)

Encephalitis (as used in medicine)

Element (as used in chemistry)

Compound (as used in chemistry)

Molecule (as used in chemistry)

Is there any evidence that both kinds of scientific terms sometimes pass into common usage and ultimately appear as ordinary words in the language? Can an ordinary word be sharpened into a scientific term and then pass back into common usage, but keep its special or "sharpened" meaning intact? Under what circumstances do you think this might take place? Can you think of any words that have followed this path?

Collect 25 miscellaneous objects, of manageable size, and exhibiting as great variety as possible. Follow through the procedure set forth in Laboratory Experience B.1.c., "Making and Using Keys", in the section on Collecting Data. Prepare a "Data Sheet" for your results, using the form indicated there for "Data Sheet No. 1."

Now, using the technique of "word sharpening," make a term for each category (subdivision) on your Data Sheet. Do this in such a way that you can refer to each group of objects by name. (For example, "rounded metal objects") Note! The names for the final group of subdivisions (the last of the branches) should be the common names of the objects (for example, "pencil," "colored crayon", "glass marble", et cetera).

Repeat the process of naming, using the technique of "gobbledygook making." Give each category on your Data Sheet a "gobbledygook" name. Devise a system and follow it. Try to be consistent in your making of "gobbledygook" names. Your names do not need to show any relationship to the nature of the objects being named, although they may do so if you wish them to. Use your imagination freely in thinking up "gobbledygook" names. The names for the final group of subdivisions should not be the common names for the objects being named, though here again they may show some relation if you wish. In any case, your set of names, should be your own. It should not follow the system used by any other student, even though you may work with a partner.

Hypothesis:

Describe the system which you followed in devising "gobbledygook" names for the categories into which you divided and subdivided your 25 objects. If, in describing your system, you find it necessary to re-examine it and improve on it, you may do so. If you do this, you should then go back and correct the original, to bring it into line with your improved system.

Follow-Up:

Read the science section of a weekly news magazine, such as Time, and science articles in your daily newspaper. To what extent do you find "gobbledygook" terms being used? To what extent do you find "word sharpened" terms? Are any of the "gobbledygook" terms on their way to becoming commonly used words in the language? Is this true of any of the "word sharpened" terms? Why do you think this is taking place in the case of these particular terms?

LABORATORY EXPERIENCE B.4.c.

WORDS! WORDS! WORDS!

Introduction:

The mastery of new words that are constantly appearing in science is a difficult task for all students. Yet vocabulary is essential for all communication. Suppose you recognize telephone and telegraph but not telemetry. Yet the beginning syllable (the prefix "tele") is the same. You recognize biology and geology, but the word herpetology is new. The ending of each word (the suffix "ology") is the same. Would a knowledge of prefixes and suffixes help you in understanding and remembering new words? Perhaps you are thinking, "Studying prefixes and suffixes should be done in English classes--let's get on with science."

There are several ways to record scientific observations: mathematical equations, graphs, and diagrams for example, but the most extensively used way is with words. Every science book and every scientific magazine or newspaper story consists of words. Even the most learned scientist finds new words when he reads new materials. Often they are such new words that they are not yet in the dictionary. Then the scientist turns to word analysis as the best method for finding the meaning of the new word. Word analysis consists of looking for the parts that a word may have: a prefix, a root, a suffix, and finding the meaning of these parts. Various combinations of these parts may make the new word.

Collecting Data:

Use a dictionary to get the meaning of the following prefixes:

ante-
anti-
bi-
circum-
dia-
fore-
hyper-
hypo-
inter-
meta-
milli-
mono-
non-
ortho-
peri-
post-
pre-
retro-
semi-
sub-
super-
trans-
tri-
ultra-
un-
uni-

These are just a few of the many prefixes used in science, but they are enough to get you started on word analysis.

The following may be used as roots (the part of a word to which prefixes and/or suffixes are attached), or they may be used as prefixes or as suffixes.

anthro-----man
astr-----star
audio-----hear
auto-----self
baro-----pressure
bio-----life
centr-----center
chrom-----color
cosmo-----world or universe
crypt-----hidden

geo-----earth
graph-----drawn, written
hetero-----other, different
iso-----equal
luna-----moon
magn-----large
meter-----measure
morph-----shape
phot-----light
proto-----earliest form
spect-----look
terr-----earth
umbra-----shadow

gram-----drawn, written, weight
helio-----sun
homo-----same, like, man
lith-----stone
macro-----large
mega-----great, million
micro-----very small
phon-----sound
poly-----many
schizo-----split
tele-----far
therm-----heat
zoo-----animal

Use a dictionary to find the meaning of the following suffixes:

-able, -ible, -ile
-ary
-er, -ant, -ard, -eer, -ist, -or
-ful, -ous
-ic
-less
-oid
-ology, -ogy, -nomy

Analyze the following words and use the dictionary to verify the meaning:

retrospect
audiometer
microcosm
heliocentric

schizoid
isotherm
cryptograph
anthropology

If "bio-" is life and "-ology" is "study of", why isn't the word spelled "bioology?"

If "ad-" is"to"or"toward," why do we write "assemble" instead of "adsemble?"

Sometimes a syllable looks like a familiar prefix, but if you analyze the word that way it doesn't "make sense". Then what should you do?

Is word analysis one good way to better understand words? Is it an infallible way? (Try word analysis of "infallible." Are spellings changed? Are there other ways to find the meaning of new words? Are there any difficulties in using word analysis? How will you know if your word analysis is correct?

Making a Hypothesis:

Make a brief statement about the use of word analysis in understanding scientific terminology. (This is another word you can analyze.)

Further Testing:

Use word analysis and explain the meaning of the underlined words in the following sentences:

He is studying the geomorphology of the Rocky Mountains.

This process can be used with polychromatic materials.

That city celebrated their tricentennial anniversary.

There is a subterranean passage.

What does the subscript mean?

Make many other words by combining prefixes and/or suffixes with root words.

Follow-Up:

Start a vocabulary list, either individually or a class list, of words that you encounter in your reading that can be understood and remembered by means of word analysis.

Keep a list of additional prefixes, suffixes, and roots that you can use in studying science words.

IDEA-CENTERED LABORATORY SCIENCE

(I-CLS)

Unit B. How a Scientist Behaves Toward His World

TEACHER NOTES

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Unit B. How a Scientist Behaves Toward His World

TEACHER NOTES

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LABORATORY EXPERIENCE B.1.a.

Recognizing Properties

TEACHER NOTES

This is a laboratory experience in which it is easy for both teacher and students to become lost is physical detail. The reason for including the observation of general and specific properties of a variety of things as a separate laboratory experience is to bring students to realize that things can be studied systematically by carefully observing their properties. These properties can then be used as a basis for their classification. Properties which are possessed in common can be used to group things. Those which are not possessed in common serve to separate them.

Classification is not an end to be pursued for its own sake. It is a device for dealing with the world, which otherwise would be too complex and difficult for meaningful interpretation or understanding. Classification is thus essentially a means of simplifying the world, and "cutting it down to our size."

LABORATORY EXPERIENCE B.1.b.

Using Similarities and Differences to Group Things

TEACHER NOTES

The goal of this experience is to bring the students to carefully observe similarities and differences, and to see how these can be used to group objects in categories.

The experience is capable of much variation. In the case of either non-living (man-made) things, or things living or once alive, almost anything can be used for comparing or contrasting. (NOTE: Do we compare things that are alike and contrast things that are different? If so, where in this laboratory experience do we compare things, and where do we contrast them?)

The only point at which it becomes important what specific materials are used is in Step Number Four. Here, the genera of trees or shrubs from which leaves or needles are obtained for comparison must be:

a. those which contain a number of similar but distinct species.
b. reasonably abundant locally so that they can be obtained without difficulty.
c. reasonably similar to but easily distinguishable from species belonging to the genus with which they are paired.

Substitutions of other pairs of genera may be made, but only if they meet these requirements. In different geographical or ecological areas, or in areas not primitively forested, such substitutes will necessarily need to be made. Where suitable species of trees or other woody plants are not available, non-woody plants may be used. Other plant parts than leaves also may be used. Flowers will work well if they are available. Leaves, of course, are less limited to season than flowers. Some seeds would make interesting materials for comparison, and possibly could be kept for utilization from year to year.

LABORATORY EXPERIENCE B.1.c.

Making and Using Keys

TEACHER NOTES

The only reason a key can be made and used is because objects can be categorized.

Our objective is the understanding of the idea of categorization, It is easy to get lost in the details of making and using a key. Do not allow yourself or your students to do this.

You may find it necessary to help students with the mechanics of recording the basis for their "either/or" choices on Data Sheet No. 1 and Data Sheet No. 2. Feel free to do this. This is an exercise in logical thinking. Your students will be able to manage it easily, once they get the knack of it. Help them at first if necessary.

LABORATORY EXPERIENCE B.1.d.

Identifying Leaves

TEACHER NOTES

If the season or the local situation makes living leaves on trees unavailable, pressed leaves may be used. If this is done, however, the pressed and mounted leaves must be carefully protected because they are very fragile. One way to do this might be to mount them on cardboard and cover them with sheets of plastic of the type used in wrapping food. An even better way would be to mount them in sheets or blocks of plastic, such as can be obtained from a biological supply house (e.g. General Biological Supply House, Inc. 8200 South Hoyne Avenue, Chicago, Illinois, or Carolina Biological Supply Company, Burlington, North Carolina).

The teacher should look for field books of trees and shrubs, other than the example indicated, and try to have more than one available. This is especially necessary for anyone located in a part of the country other than the northeastern United States and Southeastern Canada. Such field books are readily available for any region where you may be teaching.

LABORATORY EXPERIENCE B.2.a.

Measurement and You

TEACHER NOTES

The goal of this laboratory experience is to help the students to understand the relative nature of measurement: the relative accuracy of the measurements we make, the relative importance of the measurements we make, and the practical limits of measurement. This understanding centers on the fact that science is necessarily quantitative rather than qualitative in its approach to the world. By its nature science is not concerned with the qualities of things, but is limited to what can be weighed, measured, counted, or otherwise quantitatively dealt with.

LABORATORY EXPERIENCE B.2.b.

Precision

TEACHER NOTES

An understanding of the mathematical concept of approximation, and of the interrelationship of size of the unit or fractional unit, absolute error, and precision, is the goal of this laboratory experience. You should make sure that you understand the concept and interrelationship yourself before you attempt to teach them.

LABORATORY EXPERIENCE B.2.c.

Accuracy

TEACHER NOTES

Although most people use accuracy and precision interchangeably, or else just speak of accuracy alone, there is an important difference.

Accuracy is determined by relative error; that is, the relationship of the absolute error to the size of the object being measured. This is a subtle but important difference.

After the students have completed these two laboratory experiences, be sure that you yourself use the words precise and accurate correctly, and insist that the students do so.

LABORATORY EXPERIENCE B.2.d.

A Way to Measure Length

TEACHER NOTES

Since the metric system and the units of American money are both based on the decimal system, keep the comparison in your own and the students' minds.

1 dollar -------- 1 meter
1 dime ---------- 1 decimeter
1 cent ---------- 1 centimeter
1 mill ---------- 1 millimeter

Conversion from the English system to the metric system and vice versa is irrelevant at this time, but it is important that you give students many opportunities to use the metric system and obtain mental pictures of the metric units.

LABORATORY EXPERIENCE B.2.e.

A Way to Measure Capacity and Weight

TEACHER NOTES

The relationship between volume (linear unit^3), capacity, and weight is inherent in the metric system, but not in the English system:

1 cubic centimeter = 1 milliliter = 1 gram of distilled water at 4 degrees C.

1 cubic decameter = 1 liter = 1000 grams of distilled water at 4 degrees C.

Understanding these relationships rather than any conversion from metric to English or the reverse is the goal of Laboratory Experience B.2.d. and B.2.e.

It should be carefully noted that no successful metric equivalents for measurement of time have ever been devised. Attempts to do so have not proved successful.

LABORATORY EXPERIENCE B.2.f.

Measurement of Time

TEACHER NOTES

Some portions of this laboratory experience: those having to do with weather cycles and with observations of the phases of the moon, will require longer periods of time than can be devoted exclusively to the experience in the classroom-laboratory. There is no reason at all, however, why the experience cannot be introduced, and some of it done, during a portion of time devoted exclusively to it; then the lunar portion of it, and possibly the weather portion also, be continued for a longer period, while the class is proceeding with another laboratory experience. Some of the work will necessarily have to be done outside the classroom in any case. These portions can be done by small project groups rather than by the entire class if this is desirable.

Under Follow-Up, an interesting experience can be carried on by studying the daily cycle of body temperature. Fever thermometers would be needed for this. A periodic check of body temperature at four-hour intervals for several 24-hour periods, by one or more individuals gives an interesting picture. It is particularly interesting to compare the records for different individuals, including both adults and children. This of course, would require outside time, and also parental cooperation. A few volunteers, however, might be willing to try it.

LABORATORY EXPERIENCE B.2.g.

Measurement Is Dependent On Physical State

TEACHER NOTES

This laboratory experience furnishes an excellent opportunity for weighing, measuring, and calculating relationships. It also gives an opportunity for students to observe margin of error. Replicating the experience, or comparing the results obtained by different individuals or teams, will emphasize both the essential repeatability of the experience and also the margin of error at the level of sophistication at which the students are operating.

LABORATORY EXPERIENCE B.3.a.

Making a Physical Model of an Atom

TEACHER NOTES

The primary function of this laboratory experience is to help students recognize the importance of making a model of things that are too tiny to be actually seen. A secondary function is to help students to understand the interrelationship of the various kinds of sub-atomic particles that make an atom. This furnishes a foundation for building a further understanding of valence and chemical combination (See Laboratory Experience B.3.b., Carbon Chains and Rings).

Although nothing is specifically introduced concerning the sizes of the various sub-atomic particles in relation to one another, and the relationship of these sizes to the size of the space within the atom, a general understanding of this may be pointed out. Specific measurements of the type used to describe these sizes need not be used, since they would be difficult to translate into student language. A realization of the relative emptiness of the space within the atom in relation to the particles that it contains is an important concept for students to grasp.

At a later point the relative emptiness of the atom can be compared to the similar relative emptiness of the space between stars. (See Laboratory Experience B.3.g., Making a Model of the Solar System).

LABORATORY EXPERIENCE B.3.b.

Carbon Chains and Rings

TEACHER NOTES

It is actually possible to lead students who know nothing about chemistry to a quite workable understanding of the chemistry of living matter by continuing the procedure begun in this simple laboratory experience. Five basic understandings must be introduced first: (1) what an element is, (2) what an atom is, (3) what a compound is, (4) what a molecule is, and (5) what valence is. With these as a beginning, without ever balancing an equation, using structural formulae and building them toward greater and greater complexity, even such complex molecules as chlorophyll and deoxyribonucleic acid (DNA) can be understood.

These structural formulae are models of molecules.

LABORATORY EXPERIENCE B.3.c.

A Very Complex Molecule:
DNA, the Substance That Carries Heredity

TEACHER NOTES

The function of this laboratory experience is to carry the students as far as possible toward an understanding of the nature of the hereditary material. The structure of DNA is a very complex concept, but the working out of it is one of the most important break-throughs in modern biological research.

The presentation in this laboratory experience is correct as far as it goes, and it should furnish a basis for students to build a further understanding at a more advanced level of study.

A good preparation for the teacher before attempting to carry through this laboratory experience is to become familiar with the chapter in The Cell (Life Science Library) to which the students are referred at the end of the laboratory experience. The teacher should also read other references which describe the structure and behavior of DNA.

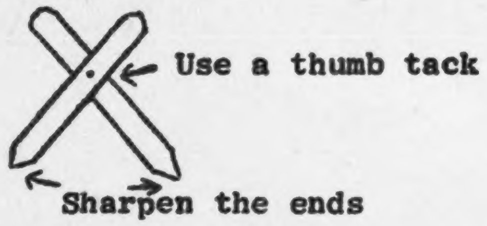
LABORATORY EXPERIENCE B.3.d.

Models of Crystals

TEACHER NOTES

We are concerned about models of internal structure that we cannot see. Mineralogy textbooks will assist you. Investigating the Earth by ESCP, published by Houghton Mifflin Company and Crystals and Crystal Growing, by Holden and Singer, published by Doubleday and Co. will be very helpful.

Make a simple caliper of two popsicle sticks for measuring the angles of the crystals.



The calcite model is actually quite complicated, and perhaps should not even be considered. It is interesting, however, and it will challenge students to use ingenuity in developing a model which fits the observations.

The combinations of silicon-oxygen tetrahedrons are also complicated, but will show how properties of these minerals are related to the crystalline structure.

Models of these more complicated crystals may be made by the teacher and exhibited after students have tried their hands at the task.

Diagrams (two-dimensional models) may be drawn of any of the three-dimensional models.

Museums often have models of crystals on display.

LABORATORY EXPERIENCE B.3.e.

Mathematics as Models

TEACHER NOTES

The mathematical models used in this experience progress from a simple formula

$$(lx = A)$$

to direct and inverse proportions.

The emphasis must be on the concept that equations and formulas are mathematical models. Physical models, mental models, and mathematical models are all important in science.

LABORATORY EXPERIENCE B.3.f.

Models for Probability: Heredity

TEACHER NOTES

Although the emphasis in this laboratory experience is on the construction and use of models, it also furnishes an opportunity for students to come to a realization that heredity and environment must interact in the development of human traits. This is an important concept, and you should point it out in connection with consideration of the multiple factor traits referred to in the Follow-Up portion of the experience. Other examples of the interaction of heredity and environment may well be discussed at the same time.

There is probably no area of biology in which there is greater inherent student interest than in heredity. So long as it is human heredity that is being considered, students' self-concept is involved. They are anxious to find out about themselves. This is particularly true of adolescents and those who are approaching adolescence. Social concerns, and those that affect marriage and reproduction are very close to them. This area is therefore one that is highly productive of questions, and is ideally suited to inquiry.

It is highly probable, therefore, that some students in the class---those that are more able and more interested---will want to go beyond those aspects of heredity that are outlined in the general laboratory experience. Further interesting possibilities are the investigation of special traits in the students' own families. Musical ability is one which may be investigated. Artistic and mechanical ability can sometimes be traced. Others are physical traits such as shape of ears and noses, and shape of hands and fingers. Susceptibility to cancer of particular types is another possibility. Students will suggest or discover others. Family pedigrees constructed from such data may constitute interesting and worthwhile outside projects.

Eye color is interesting but often turns out to be more complex than is commonly thought. It is determined primarily by a single pair of genes: brown (B) and blue(b), in which brown is dominant to blue. In some families this relationship can readily be seen. There are, however, a number of pairs of modifying genes that also enter the picture. These serve as diluters and intensifiers of color, producing various shades of color between blue and brown. Some of these, such as gray and blue-green,are difficult to interpret.

Red hair is also interesting. Non-red is dominant to red, and red pigment in hair depends for its expression on the extent to which it is not covered up by dark pigment (brown or black). Thus there are various shades of auburn in hair which constitute red in combination with dark pigment.

Blondness and brunettness in hair pigmentation can be explained fairly well on the basis of two pairs of genes operating together without dominance (in multiple factor fashion). Various combinations of these give a series of shades of lightness and darkness ranging from light blond to dark brunette.

All of this material will be of interest to the students if you wish to take time to go into it, and if they wish to pursue it.

LABORATORY EXPERIENCE B.3.g.

Making a Model of the Solar System

TEACHER NOTES

An important understanding that students can get from this laboratory experience is a realization of relative sizes and distances. The sizes of the bodies that space contains (suns or stars, planets, moons) is relatively insignificant in relation to the size of space itself. When students discover that it is not possible to use a single scale to represent both relative sizes and relative distances in a physical model, they have taken a major step toward realizing this. Another step is taken when they attempt to construct a mental model based on using a basketball, a familiar object, to represent the sun, and base all other sizes and distances on this.

Space is vast and relatively empty. Students may be led further to realize that this is true not only at the level of stars, planets, and moons, but also at the level of neutrons, protons, electrons, and other sub-atomic particles.

LABORATORY EXPERIENCE B.4.a.

Changes in Language

TEACHER NOTES

This experience can be used to give students a real understanding of evolution, without any reference to the evolution of man and other animals, or plants, which might be controversial. It may easily be expanded to include the evolution of all of the things that man uses: clothing, tools and machines, methods of heating and lighting, transportation, communication, weapons, even the ideas that shape peoples' actions.

In the case of these things we have a kind of "evolution by proxy," but it exhibits the same characteristics as the evolution of living things: mutation, change in response to the challenge of the environment, survival, and perpetuation of that which "works" (is operationally valid), and the preservation of archaic forms in relict areas. In this kind of evolution, however, change takes place much more rapidly than in the evolution of animals and plants in nature. Why?

LABORATORY EXPERIENCE B.4.b.

Scientific Terminology

TEACHER NOTES

This laboratory experience may serve not only to help students understand how scientific terms are developed, but also to increase students' scientific vocabulary. The list of scientific terms in the first section under Collecting Data may be expanded by the teacher to any extent desired.

In the second section under Collecting Data, the categorization of the 25 miscellaneous objects may be carried farther, with the making and use of a key, as in Laboratory Experience B.1.c., "Making and Using Keys." If students are not able to collect 25 miscellaneous objects for use in this section of the laboratory experience, a smaller number of objects may be used. The larger the number, however, the better will be the results.

LABORATORY EXPERIENCE B.4.c.

WORDS! WORDS! WORDS!

TEACHER NOTES

Word analysis can be one of the most useful tools that a student can learn to use. It helps not only with reading and understanding, but also with spelling. Scientific terms are generally easier to pronounce and spell than non-scientific words of corresponding length and complexity. This is due to the fact that they are generally made up of pronounceable and spellable parts. Once these parts are learned they can be combined in a wide variety of relationships to make meaningful new words.